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METALS and ALLOYS

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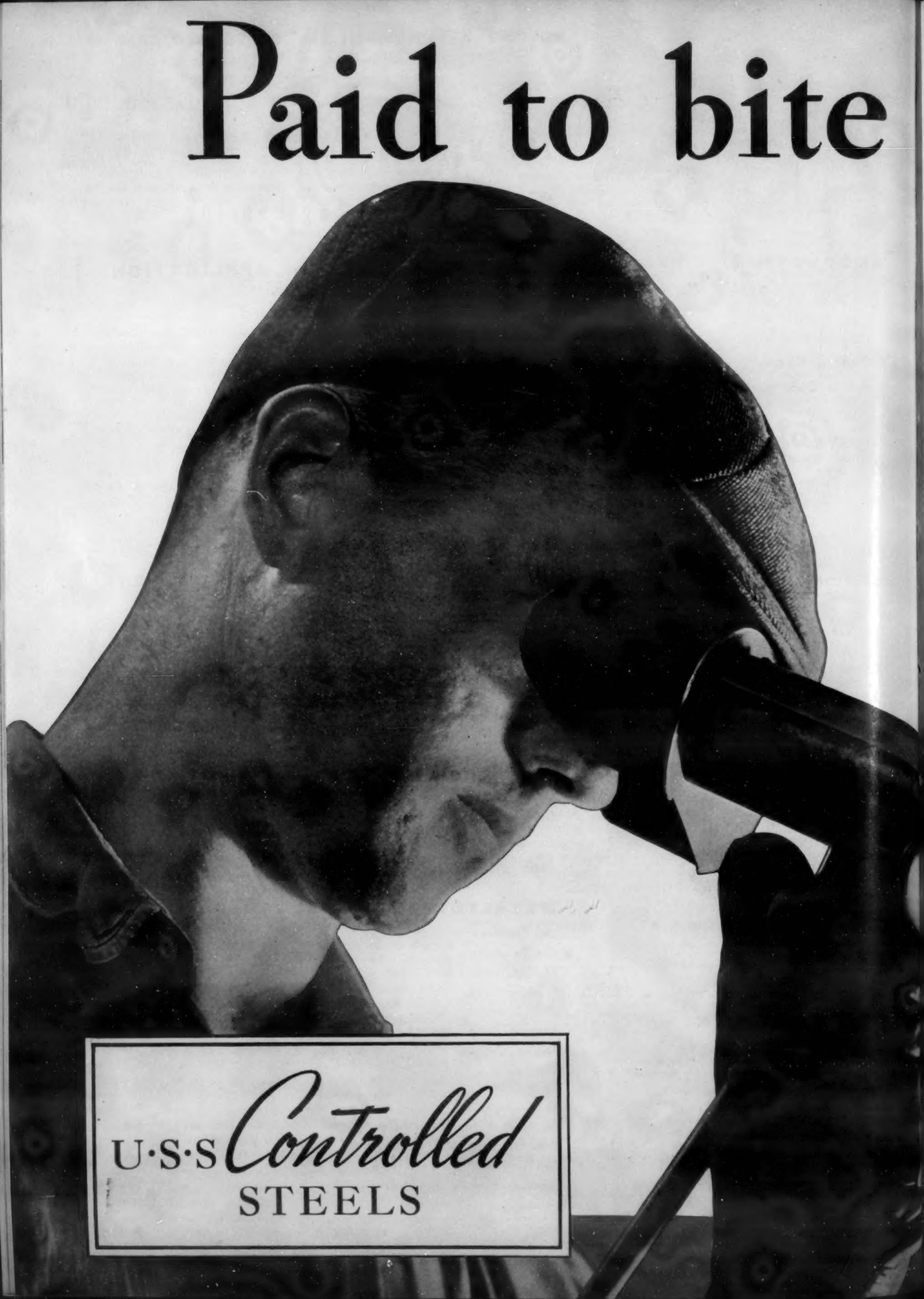
ARTICLES

METALLURGICAL ABSTRACTS



Paid to bite
U·S·S Controlled
STEELS

METALS AND LUBRICANTS FOR

BEARINGS AND GEARS

AN EXTENDED ABSTRACT

Part I

by R. W. Dayton

Battelle Memorial Institute,
Columbus, Ohio.

When a symposium of some 125 papers in an important field is carried out, especially in a foreign country, formidable indeed is the task of obtaining even the high spots of the authors' discussions. In each paper fundamental facts or the results of extensive research by authoritative workers may be found. The subject of metals and alloys in bearings and gears, together with the closely related topic of lubricants, is an exceedingly broad and complex one.

It is one function of a metallurgical engineering journal to make it easier for its readers to glean the highlights of so comprehensive a symposium. In this article we present an extended abstract of the symposium, prepared in a highly creditable manner by Mr. Dayton. It will appeal to steel mill engineers as well as to metallurgists. The American Society of Mechanical Engineers is distributing the symposium.—The Editors.

IN BEARINGS, GEARS, AND THE LIKE, the materials—i.e., the metals and the lubricants—and the engineering design are so intertwined that all are properly considered together. It was from the broad engineering basis that the British Institution of Mechanical Engineers held a symposium last fall which included 125 papers, published in four volumes totaling 903 pages, dealing with almost every phase of the whole subject.

The papers presented in this symposium are of great importance to one whose interests lie primarily in the field of lubrication. All branches of that subject are covered, some in great detail. The metallurgical information is chiefly incidental; only a few of the papers deal primarily with metallurgical subjects. This review is intended for the metallurgical engineer and aims to pick out the metallurgical high spots against the general engineering background.

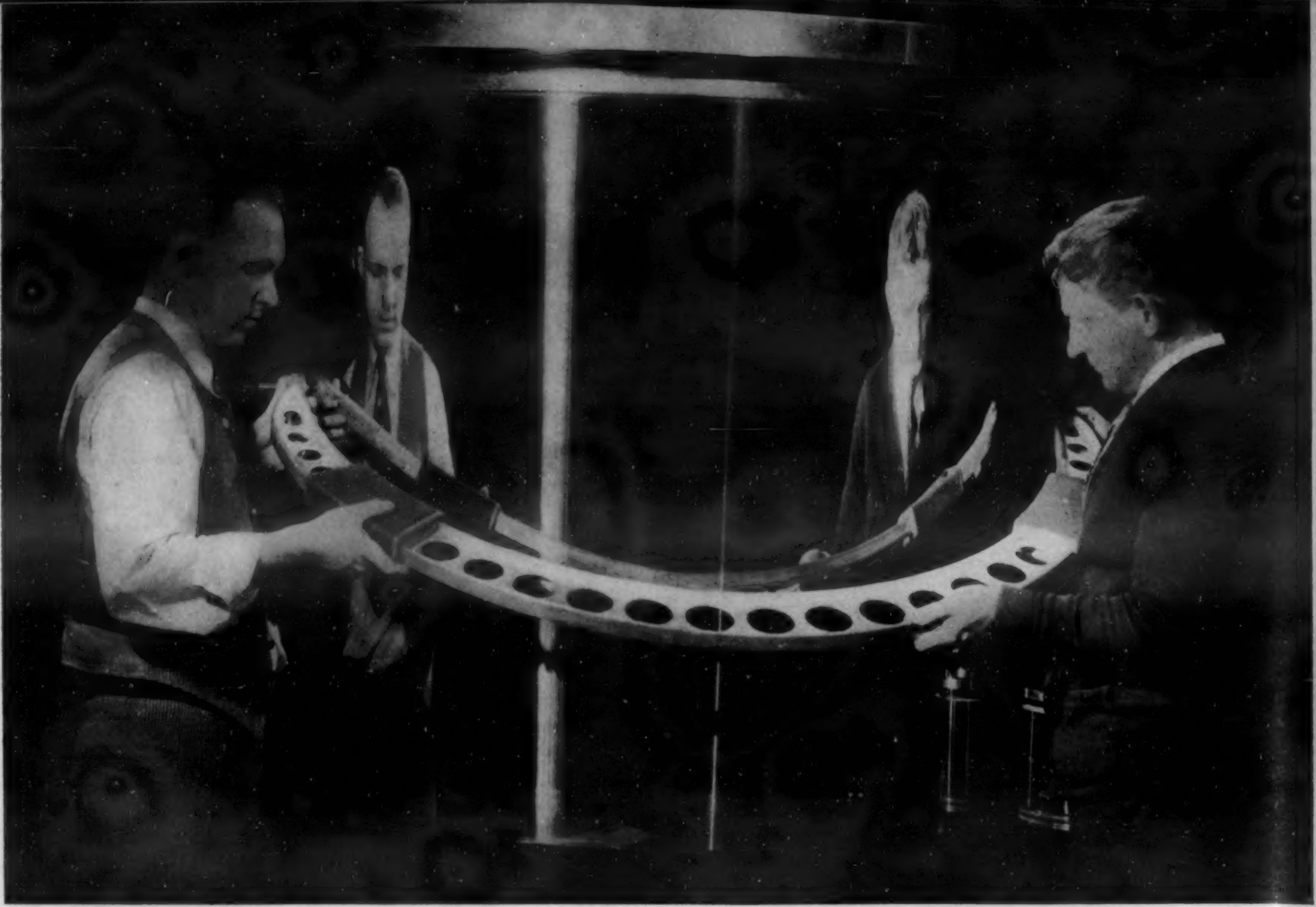
From the reviewer's own experience in the study of the material for abstracting, the metallurgical engineer concerned with bearings, gears, etc., who reads the whole symposium, will find his horizons usefully broadened.

FUNDAMENTAL

THE BASIS of modern lubrication is the mathematical theory developed by Osborne Reynolds from the experiments of Tower. As many of the papers in the first group of the symposium show, this theory has been somewhat modified in later and more rigorous calculations. However, Reynolds' theory still maintains its general characteristics. This theory is limited, inasmuch as only friction in the fluid film region of lubrication can be found by it, whereas sliding friction can be of either of three types—fluid film, boundary film, or dry.

An understanding of the first two types of lubricated friction can be gained from the following example of a shaft turning in a bushing at a constant speed and using oil of a constant viscosity. If this bearing is unloaded, the shaft will assume a central position in the bushing, with a film of oil, of uniform thickness, separating the shaft from the bearing. If the shaft is now placed under increasing loads, the shaft and bushing will be forced closer and closer together. If measurements of the coefficient of friction are made, it will be found that the coefficient is decreasing as the load increases, up to a certain maximum load. This region of decreasing coefficient of friction with increasing load is that of fluid film lubrication, so called because there is no metallic contact, and the frictional drag is entirely due to the viscosity of the lubricant. This friction may be calculated from hydrodynamic theory, such as that of Reynolds.

If the load is increased beyond a certain maximum, which varies with the test conditions, the coefficient of friction will begin to increase with increasing load. This region is that of boundary film lubrication, so called because



Typical Alloy Steel Sleeve for Morgoil Bearing (Courtesy: Morgan Construction Co., Worcester, Mass.)

the oil film is supposed to be of only molecular dimensions, retained on the metal by adsorption. In this region the oil film is sometimes broken through, and metallic contact occurs. At the region of change between fluid film and boundary film lubrication, there is, therefore, a minimum coefficient of friction.

It can be appreciated that the maximum load a bearing can stand without entering the region of boundary film lubrication is important in certain bearings that must run for long periods of time without appreciable wear, such as steam turbine bearings. The metallic contact which occurs in boundary film lubrication will give relatively high wear and must, therefore, be avoided. Falz,[11] Heidebroek,[113] and Jakeman and Fogg[16] all say that the minimum coefficient of friction will occur at higher loads with smoother mating surfaces. This, of course, is obvious, since smooth surfaces can run at closer average distances without metallic contact than rough ones. It should be mentioned here that a ground surface cannot, in view of the small distances under consideration, be regarded as a particularly smooth one. It can further be appreciated that run-in bearings can stand higher loads than new ones, since running-in is a process of smoothing. The most important surface is that of the harder material; the softer one can be smoothed more readily in running.

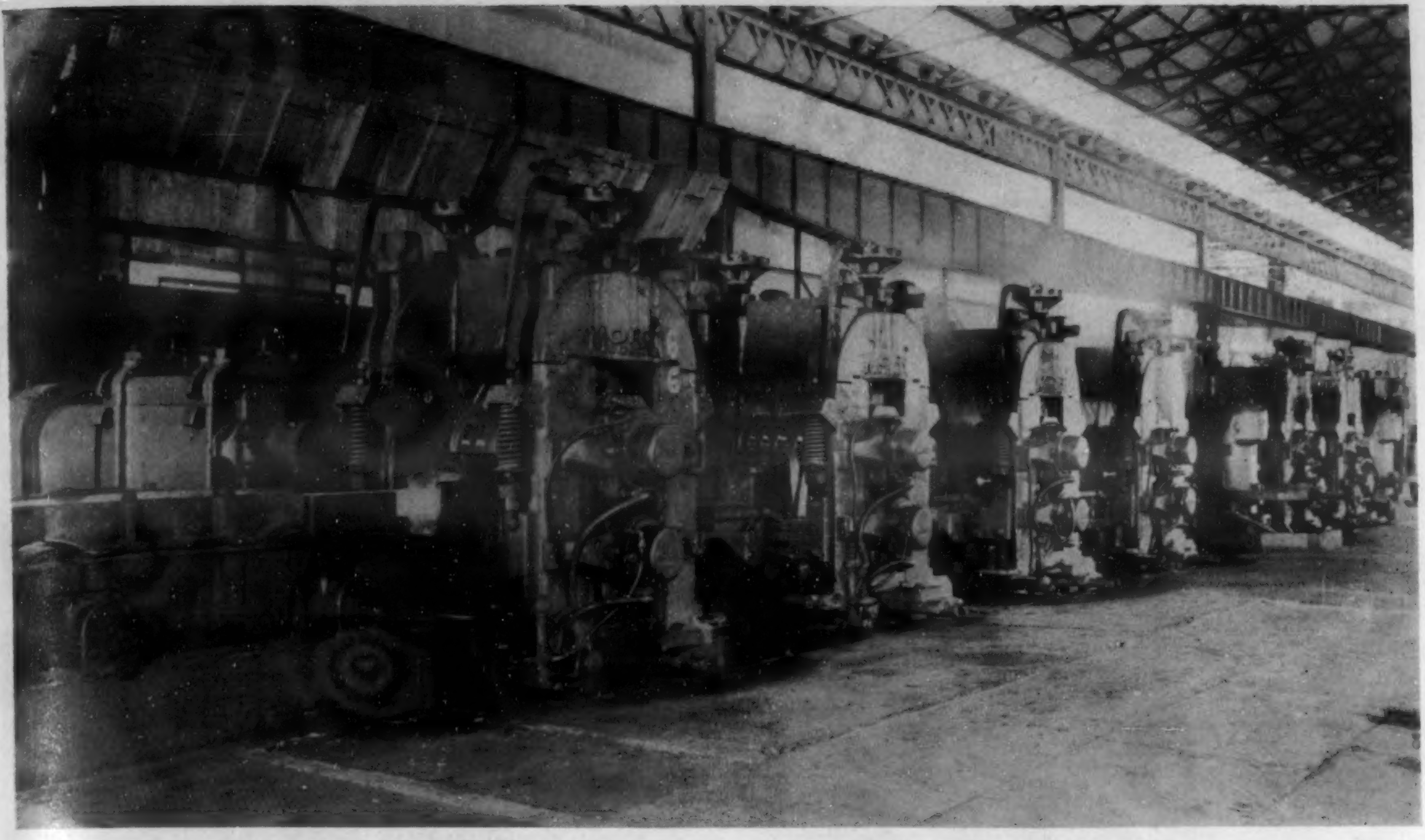
Fluid and Boundary Film Friction

Fluid film friction requires least of the metals, since they are not in contact. Wear is low unless there are abrasive particles in the lubricant, and comparatively little frictional heat is developed. Bearings working under these conditions will last many years, excluding accidents.

With boundary film lubrication, much more is required from the metals, since wear is appreciable and any galling (local welding of the rubbing surfaces) or seizing (a severe case of galling which stops the sliding motion) tendencies soon become apparent. Gears, piston rings, and rolling mill bearings all work under boundary film lubrication.

Higinbotham[54] gives data on the coefficient of friction for the various types, as follows: For fluid film lubrication, the coefficient of friction is generally 0.001-0.005. For boundary film, it is 0.01-0.10, and for dry friction 0.1-0.3. He mentions that colloidal graphite reduces friction in the boundary region to 0.005-0.01 and that it likewise reduces wear. Operation in the fluid film region, of course, is not altered by colloidal graphite. Fogg[110] measured boundary friction in an oscillating bearing machine, excluding any possibility of fluid film friction, and found it to be 0.10-0.14 and to vary but little with speed, temperature, and load.

Neely[118], measuring wear of hardened steel against phosphor bronze in the boundary film region, found that for any lubricant the coefficient of friction was constant, and the amount of wear was proportional to both the distance of sliding and the load. That is, a certain coefficient of wear could be obtained for any speed of rubbing and combination of metals and oil. Unfortunately, there were erratic variations of this coefficient of wear with speed of travel, so that the results do not assume so much importance as they otherwise might. Neely also found that the finish of the hardened steel was very important; a mirror finish on the steel track gave a somewhat lower coefficient of friction and much less wear than a ground surface, and the effect of addition agents in the oil was much less pronounced. He attempted to measure the wear of cast iron in the same machine but found it to be too small under the conditions of test to allow accurate measurements to be made. The results to date are very interesting, and when Neely has completed work now in progress, much more may be known of the mechanics of wear than at present.



A Six-Stand Billet Mill Equipped with Morgoil Bearings (Courtesy: Morgan Construction Co., Worcester, Mass.)

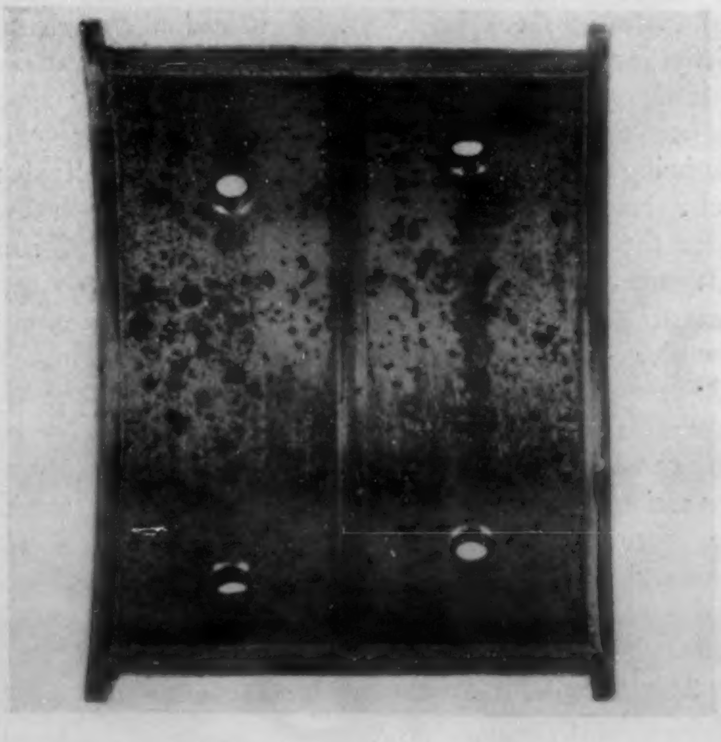
High Temperatures at Rubbing Surfaces

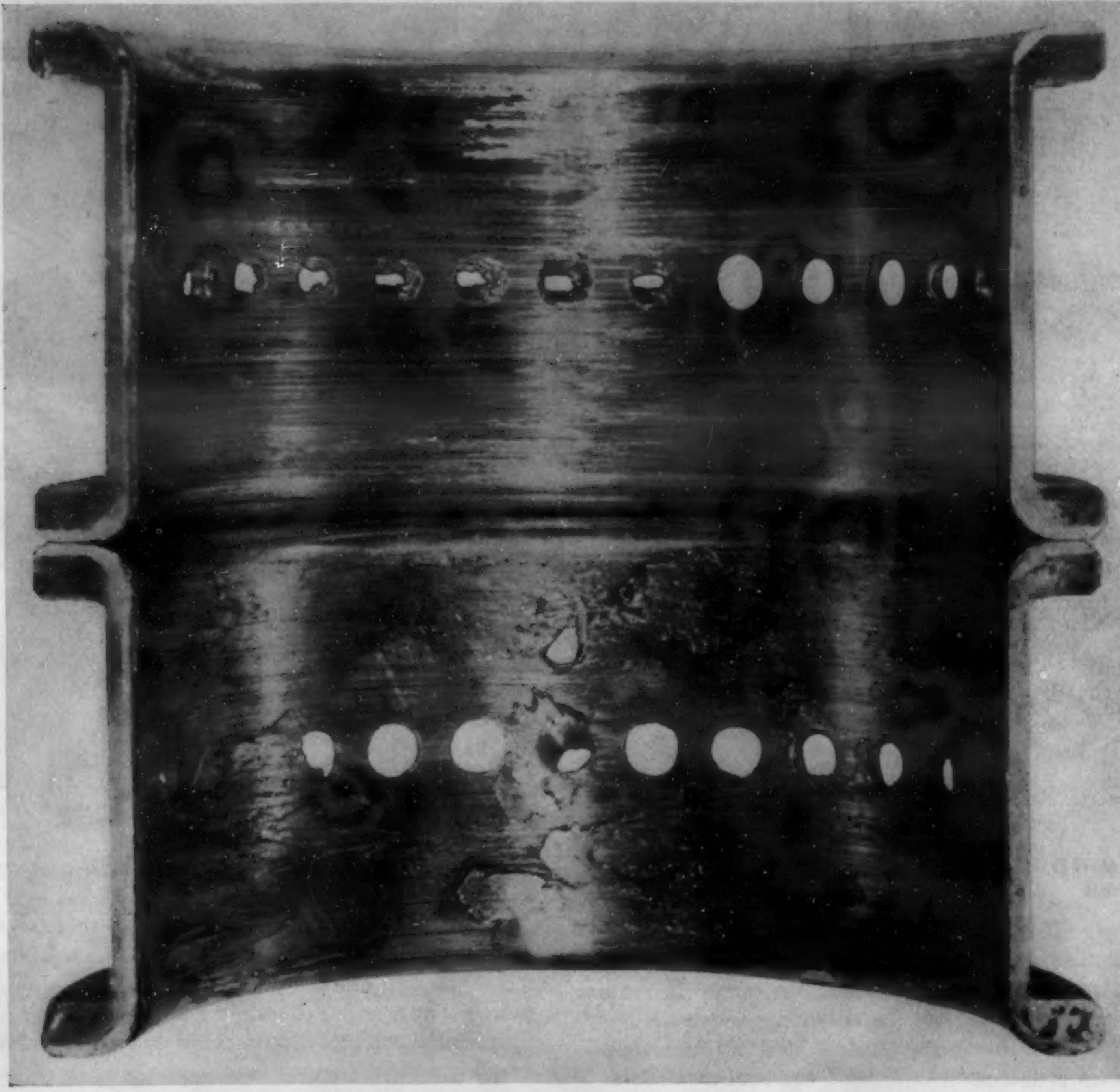
A very significant fact was brought out by Bowden[103] who found that the heat at the rubbing surfaces of two metals can reach very high temperatures, even when the surfaces are lubricated. Data were shown in which the rubbing surface of constantan against steel reached 1000 deg. C. At a certain speed and load, the temperature was about 750 deg. C. with no lubricant, 450 deg. C. with a good commercial lubricant, and 250 deg. C. with oleic acid. Further data showed that a temperature of the melting point of lead was readily reached with lead sliding on steel. This makes it seem that very high temperature properties of metals may be important in bearing studies. The usefulness of this portion of the paper, which was a review of previous work, was diminished by a lack of data on testing methods and specific loads. Work which was reported here for the first time did not have this fault. Bowden goes on to the logical conclusion of this work, that is, to show that the surface flow caused by rubbing one material on another always occurs on the lower melting one, whether it be the harder or softer of the two.

Further data showed that sliding was a process of alternate slipping and sticking, not a smooth process. After a slip, very high temperatures are reached, and it is here that galling and wear occur.

Finch and Zahoorbux[109] state that electron diffraction shows a Beilby layer on run-in bearing surfaces and feel that this surface should be present on completion of an ideal running-in process. This seems to be rather loose thinking. *If* electron diffraction does show truly amorphous metal (such as the Beilby layer is supposed to be), which is not proved, all this means is that certain bearing materials, subjected to a polishing action, obtain a polish film. The fact that a polish film is smooth is undoubtedly important, and the importance of smoothness is well recognized. Whether or not the film is amorphous is not important, since one of our best bearing metals—babbitt—could never have an amorphous layer under ordinary service conditions, since it recrystallizes at such low temperatures. Finch and Zahoorbux show evidences of arrangement of oil molecules on a metal surface and show that a graphite film is obtained on cast-iron bearing surfaces using any lubricant, as well as on surfaces of other metals when a graphitized oil is used.

This is an Engine Bearing and the Foreign Particles were Introduced through the Oil Stream. The engine had evidently not been properly cleaned after a cylinder regrind. (Courtesy: Federal-Mogul Corp., Detroit.)





This Shows the Condition of a Cadmium-Silver Connecting Rod Bearing which was Assembled without Sufficient Oil Clearance. The lining metal has been practically completely wiped out of the upper half and carried around and deposited in irregular sheets in the lower half. (Courtesy: Federal-Mogul Corp., Detroit.)

COPPER ALLOYS

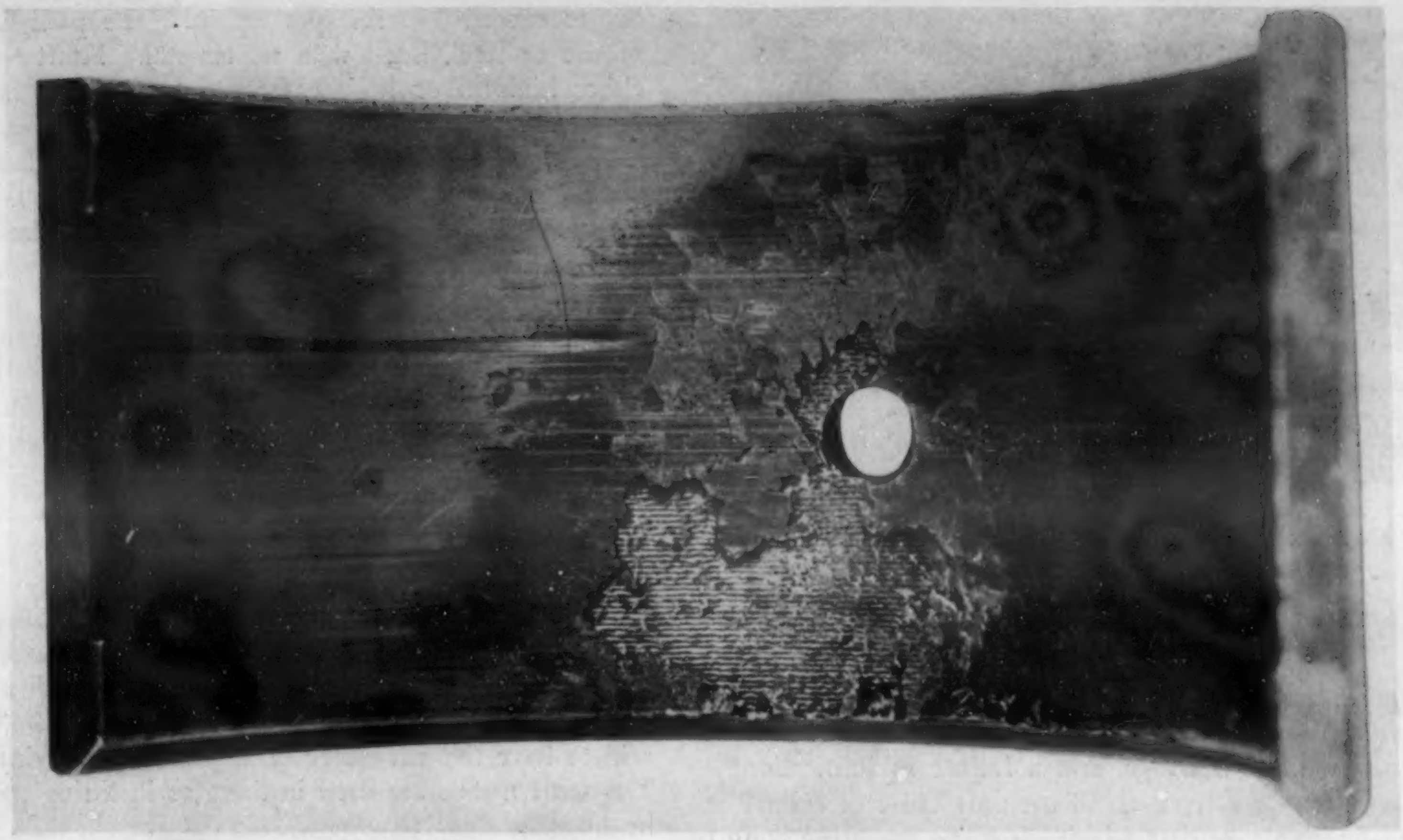
ONE OF THE few papers devoted primarily to metallurgy is that of Neave and Sallitt[25] who discuss the application of various copper alloys. Low-lead alloys are used chiefly for heavy loads and low speeds. Large amounts of lead extend the field of application to higher speeds. Copper is chiefly used in the alloyed condition, one exception being the use of an electro-deposited film on hardened steel to steel parts to assist wearing-in. Alpha tin bronzes, where the Cu/Sn ratio is greater than 93/7 (and somewhat dependent upon the rate of cooling), have good strength properties and are successful bearing bronzes. Chromium and iron additions to these alloys are helpful for high pressure service. These alpha bronzes can be used annealed, and sometimes are, but in this form are not generally considered as good as cast alloys. Phosphorus additions assist in the removal of tin oxide, which is thought to give scoring tendencies. Higher tin bronzes are used where rigidity is required. Large amounts of lead, combined with low tin, enable bronzes to be used at high speeds. These are called plastic bronzes and may contain 5 to 25 per cent Pb. Examples are: 80 Cu, 10 Sn, 10 per cent Pb; and 70 Cu, 5 Sn, 25 per cent Pb. Higher lead and lower tin alloys are used as steel-backed connecting rod bearings. These may contain 25 to 40 per cent lead and less than 1 per cent tin. The steel shells are lined at 1200 deg. C. in a reducing atmosphere. Although additions, such as 2 per cent Ni, are sometimes used to prevent segregation, it is better to keep additional elements very low.

Porous bronzes, made by compressing and sintering copper, tin, and graphite powders, can contain up to 30 per cent of oil. At light loads they do not require lubrication but can be used up to 4,000 lb. per sq. in. with an external oil supply.

The balance of the papers are best considered according to application.

JOURNAL AND THRUST BEARINGS

JOURNAL BEARINGS may fail by seizure, wear, fatigue, or melting out. Certain generalities may be drawn concerning all types of journal bearings. Falz[11] enumerates some of these, as follows: The clearance should be just



This Bearing was Used on a 4-in. Diameter Crankpin with 0.0015 Clearance. With 0.004 clearance, normal life was obtained. (Courtesy: Federal-Mogul Corp., Detroit)

large enough to avoid metallic contact and wear, and possible seizure. Excessive clearances will give poor load-carrying ability. Jakeman and Fogg[16] give data which illustrate this last point. Falz also points out that the mating surfaces should be as smooth as possible if wear is to be kept low and recommends that journals be lapped, since a ground shaft will give very high wear, especially on soft bearings. Jakeman and Fogg have also found that the degree of finish influences the load-carrying ability of a journal bearing, and evidence which Clayton[8] gives can also be interpreted to show the same thing. Clayton tested bushings at increasing temperatures up to the point of seizure and found that this seizure had the effect of increasing the load-carrying ability of the bearing. Clayton found a small change in shape due to the seizure to which he attributed the increased safety of the bearing, but the polishing effect of steel on hard bronze at incipient seizure might also explain it.

Stanier[37] mentions another point which often causes bearing trouble. He remarks that on locomotive journals the critical time for the bearing is when the locomotive is slackening speed and the bearings and lubricant are still hot. The effect of decreasing speed, at a constant load and lubricant viscosity, is to tend more and more towards the region of boundary lubrication. If the region of boundary lubrication is entered, white metal bearings are severely taxed, due to the high heat formation in this region. This fact accounts for part of the large factor of safety that should be present in bearings started and stopped under load.

Welter and Brasch[40] suggest very high pressure lubrication at the load line to assist starting and stopping. This would tax the bearings less severely in starting and stopping but, of course, could only be used in very special cases. This method of attack was developed chiefly to overcome the high friction losses of journal bearings in starting and stopping, a characteristic in which ball or roller bearings are superior, and was found to be a very satisfactory solution. Hanocq[84] compared, at the same speeds and loads, a railway journal bearing with a roller bearing of the railway type, and found that the journal bearing had less friction and a higher load-carrying capacity.

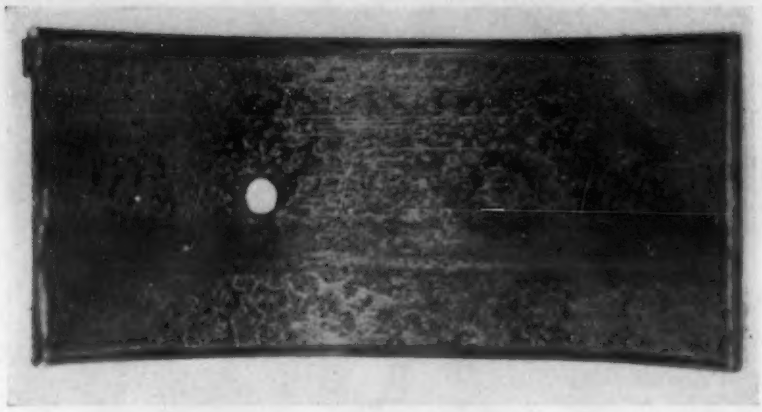
Meyer[23] found a means of using ball bearings on hot shafts, using a sleeve which prevents great heat flow to the inner race. Without this sleeve, the inner race expands and diminishes the clearance, ruining the bearing.

Condition of Lubricant on Journal Bearings

Again considering journal bearings, the condition of the lubricant is of great importance. Impurities in the oil, such as dirt, water, etc., can cause a great deal of trouble. Of six papers on the filtration of oil, the conclusion was reached that two types of filters were desirable, one through which the total oil flow should pass to remove large particles, and a by-pass filter which should remove the finest particles but which can handle only a small fraction of the total oil flow. Three types of filters were discussed. Beale[44] and Pickard[65] mention an edge type of filter using paper disks, which is said to be the only type which will remove the finest particles. Flowers,[51] Cahill,[46] and Dolton and Mackegg[49] discuss centrifugal separators, which will remove water as well as sludge and which work very fast but do not remove the finest particles. de Langen[58] recommends a magnetic filter for installations where iron particles would be the chief source of wear, such as in gear operation or running-in.

Fogg and Jakeman[52] show the very harmful effects of small amounts of water on the lubricating value of oil; 0.02 per cent has a noticeable effect; 0.05 per cent reduces the seizure temperature from 200 to 141 deg. C.

Certain types of bearings are designed to run for extremely long periods. In this class are journal and thrust bearings for steam turbine machinery. These bearings are



From the "Scurvy" Appearance of this Bearing, it might be Concluded that the Bearing Metal was at Fault in Some Way or that the Babbitt was Corroded. Under a high-power microscope, the condition was found to be due to imbedded particles of cast iron. (Courtesy: Federal-Mogul Corp., Detroit.)

so designed that they operate under fluid film lubrication and have a plentiful supply of clean oil. Almost no wear will occur in these bearings, and a failure in lubrication, which is extremely rare, is about the only cause of failure. Guy and Smith[14] give data which show the operating conditions for steam turbine journal bearings. They work at high speeds, up to about 157 ft. per sec., and low pressures, 57 to 150 lbs. per sq. in. The l/d ratio is high, normally 1 to 1¼. The minimum is 0.75 for turbine bearings; it is as high as 2 for turbo-generators. The clearances vary from 0.001 in./in. to 0.003 in./in. The average is about 0.002 in./in. Whitemetal journal bearings are almost universally used. Soderberg[35] recommends a cast steel shell in which to line whitemetal, since a better bond can be obtained than with wrought steel. Guy and Smith[14] use either cast iron or steel. They also give limits for whitemetal composition, which is usually a high tin babbitt, 76 to 86 per cent Sn, high in tin for high temperatures, 6 to 14 Sb, 4 to 9 Cu, 0-16.5 per cent Pb. Lining is done either by centrifugal or stationary casting. Soderberg mentions that the use of lead-base whitemetal has been discontinued, so that previous troubles with the formation of lead oleate are no longer important. Guy and Smith state that the thickness of the whitemetal is 3/16 to 5/16 in. for a 4-in. shaft, ¼ to ½ in. for a 12-in. shaft.

The oiling systems are designed to feed clean oil under pressure to the bearings. Too much oil[14] will increase friction losses greatly, and this loss is only partly due to the increased viscosity of the oil, caused by keeping the bearings cooler than when less oil is circulating. Soderberg states that corrosion troubles have been intensified with the new solvent-refined oils. Although copper intensifies the sludging through catalytic action, brass is still not excluded from the oiling systems.

Tilting Pad Bearings

Tilting pad bearings are standard for thrust bearings in steam turbine machinery due to their greater safety over plain collar thrust bearings. Tilting pad bearings are used except in some isolated cases of small machinery. Gibson[13] remarks that plain collar thrust bearings are not used at over 50 lbs. per sq. in., whereas pivoted pad bearings have been tested at up to 12,000 lbs. per sq. in. However, specifications rarely call for more than 500 lbs. per sq. in., and where the shaft must start rotation under load it is well not to exceed 350 lbs. per sq. in. The pads are either bronze or steel, lined with whitemetal. Kraft[19] says that either high-tin or high-lead whitemetals have been used for surfacing the tilting pads. Dowson[9] used a high-tin babbitt. It is again to be supposed that a high-lead babbitt may give trouble from lead oleate formation. Kraft[19] states that the thickness of the babbitt should be small so that, if the babbitt melts out, the results will not be disastrous. If this happens, bronze-backed pads should be preferable to steel-backed ones. Freeman[53] states that with marine thrust bearings 14 cases have come to his attention in which the whitemetal has dragged or run. This is due to the high temperature at which the thrust blocks work.

The principles of the tilting pad bearing are incorporated in another type in which the pads are rigid and machined to the correct taper, as mentioned by Linn and Sheppard[20].

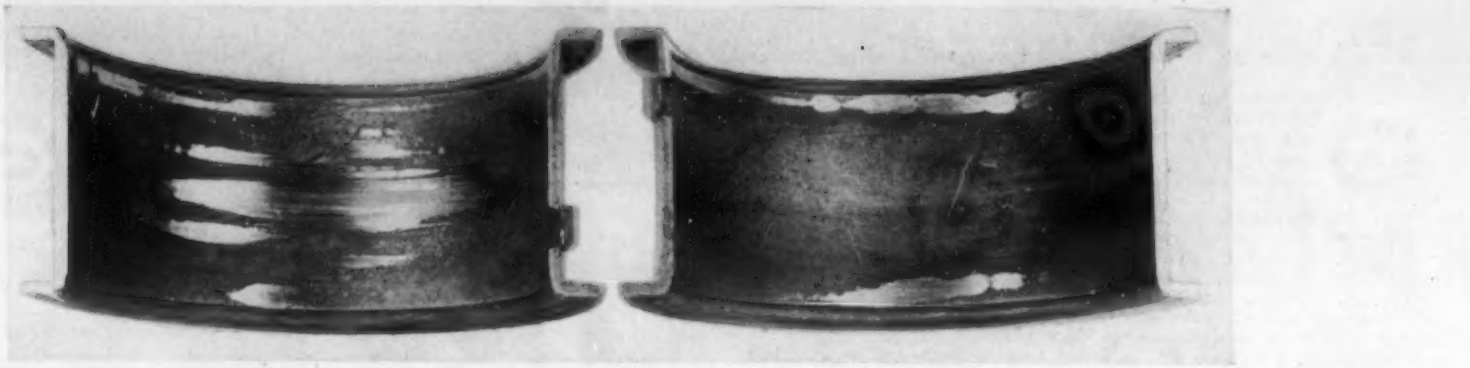
Tilting pad bearings can be used for journal bearings (Gibson[13], Mitchell[24]) but have the disadvantages of insufficient rigidity, poor heat flow, and the inability to carry reciprocating loads without ridging the housing. They are said to have the advantage of higher load-carrying ability. The same metals are used in them as in tilting pad thrust bearings.

Other types of journal bearings, of which rolling mill bearings are a good example, work under high pressures at low speeds and do not operate under fluid film but boundary lubrication. Here excessive wear, galling, and seizure are common (Thomson[39]) when metal bearings are used. For this reason, non-metallic materials are being used much more commonly for such applications. Statements were made by Rochester[31] that fabric was more suitable than metal for any type of journal bearing, but friction measurements by Thomson[39], comparing bronze with fabric bearings, showed that the friction was less with the bronze under fluid film lubrication and that bronze would stand higher pressures without entering the region of boundary lubrication. However, seizure was more sudden and severe with the bronze. The advantage of fabric over bronze for rolling mill bearings was that these bearings work a part of the time under boundary lubrication, and here the fabric bearings were superior. Smyth[34] reports 50 per cent savings, Rowell[32] 15 to 80 per cent savings in power by using fabric instead of metal. Smyth[34] further says that fabric increases bearing life 14 times and shaft life 6 times. Rochester[31] says that the bearings keep the roll necks polished, as does Eyssen.[10] A large flow of water is required[31] to keep the bearings cool, or else they char.

Rubber As a Bearing Material

Rubber is another non-metallic material which is replacing metal in some bearings. Rubber is particularly useful in places where abrasive material may come in contact with the bearing, or where water is a more convenient lubricant than oil. Fogg[12] lists as suitable applications ship propellers and water pumps. Grit does not give much scoring. Brazier and Bowyer[5] support these views.

Large-end connecting rod bearings in internal combustion engines also received considerable attention in the Symposium. Such bearings work under high pressures, temperatures, and speeds, and are subject to many types of failure. Wear is discussed by Mickelsen[60], who says that inertia loads cause the greatest wear and that wear is incurred in continuous running as well as some in starting



Corroded Cadmium-Alloy Bearings. The dark areas are etched, rough and blackened. The light areas are actually bright and shiny since the rotating shaft has rubbed off the etched and blackened surface. This condition is caused by the attack of harmful acids which are probably of petroleum origin. These acids may be formed even in good mineral oils if excessively high *operating temperatures exist. (Courtesy: Federal-Mogul Corp., Detroit.)*

and stopping. He then argues that since continuous running on boundary friction is out of the question, wear is presumably due to abrasive solids in the oil which are larger than the minimum clearance. This is fully in accord with the statements made in the papers on oil purification. Another failure which occurs in this application is the cracking of babbitt. Dicksee[48] says that the oil cannot be over 100 deg. C. with whitemetal, except for short times, because of this cracking. Williams[125], using a dummy engine with a piston to give a maximum pressure of 5,850 lbs. per sq. in., a mean pressure of 3,080 lbs. per sq. in., at 3,300 r.p.m., with a rubbing speed of 109 ft. per sec., investigated the effect of bearing temperature on bearing life and found a drastic inverse ratio. At 70 deg. C. the bearing life was 95 hrs.; at 135 deg. C. it was 14 hrs.

Causes of Cracking

Macnaughtan[22] discusses causes of cracking and concludes that it is a fatigue phenomenon. Flexing is sometimes a cause of the fatigue stress, but this is not always true, and he cites one case in which a decreased rigidity (which would increase flexing) increased bearing life. Aside from flexing, the ways of obtaining fatigue stress are difficult to find. Little fatigue data for babbitts at elevated temperatures are available, but it can be expected that at about 150 deg. C. babbitts have about 40 per cent of their room temperature strength. Lead is not helpful below 150 deg. C. and is deleterious above that. Cadmium improves the strength of babbitts up to 150 deg. C.

For higher output engines, particularly new aircraft engines, babbitt is too weak. Bass[43] says that copper-lead and cadmium bearings are now being used in big-end connecting rod bearings for aircraft, due to their mechanical superiority over whitemetals. These require special lubricants to prevent corrosion, which appears above 130 deg. C. He says that new materials are being developed to overcome these difficulties but does not mention what these are. Jones and Turner[56] say that the Napier Dagger aircraft engine now uses a steel-backed copper-lead for their big-end connecting rod bearing. *(To be concluded.)*

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Editorial

(Continued from page A31)

across the water to belittle, or perhaps not to give credit for, American productive research and its industrial application, sufficient evidence will be at hand to correct such a mistake.—E. F. C.

Metal and Racial Alloys

Considerable prominence has been given in the daily press to an editorial in the *New York Journal and American* for Sunday, July 31. It was entitled, "The American Race." Briefly, it was argued that it is futile for Hitler, or trailing after him, Mussolini, to make the world safe for the Aryan race. Nor should it be possible. "If the Aryan race cannot take care of itself in competition with other races, then it is an *inferior* race and should not be preserved." "The American is what it is today, the strongest and richest, and the most progressive, and the most prosperous nation in the world," because it is not a so-called "pure" race, it is not a deteriorated inbred race and it is not a 100 per cent Aryan nor any other race. "It is because we are a *racial alloy*"—with the superior strength of an alloy, due to the absorption of the mental and physical assets of many other great peoples.

A leading orchestral conductor of Europe, who has directed orchestras in nearly all musical world centers, recently was quoted in a published interview that the New York Philharmonic Symphony Orchestra is the finest he has ever presided over. German, Italian and other foreign orchestras are largely made up of their own nationals. But the American orchestra contains musicians from many lands. To this fact he attributes its superior tonal and other qualities. Can we call this "alloyed music"?

In the metallurgical world there is a parallel analogy. Iron or plain carbon steels have their characteristic properties. However, by alloying them with nickel, chromium, molybdenum, vanadium, copper, phosphorus and so on, these properties are greatly improved and products are obtained that meet modern industrial needs. And they are still further improved by heat treatment; in a similar way the American race is improved by the "heat treatment" of education and experience.—E. F. C.

Symposium on Impact Testing

AN EXTENDED ABSTRACT

by S. L. Hoyt

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A. O. Smith Corp., Milwaukee

So that "he who runs may read," we have been able to present here an extended abstract of the important Symposium on Impact Testing which was a feature of the annual meeting of the American Society for Testing Materials at Atlantic City, June 27 to July 1, 1937. The impact test has come into much wider usage in recent years which makes the highlights of the symposium valuable to testing and other engineers. We feel that we are fortunate in having Dr. Hoyt as the reviewer and abstractor—one who ranks very high in an understanding of this subject.—The Editors.

AT THE ANNUAL MEETING of the American Society for Testing Materials 16 years ago, the (so-called) impact test was discussed at a formal symposium. The general results of that session were largely negative for they led neither to general recognition of the value and utility of the test nor to the establishment of a standard test for this country. The reality of the effect to which the test relates appears not to have been discovered or, if it was, it was lost in a maze of discordant experiences and conflicting opinions. At the annual meeting one year ago this subject was again treated in a round table discussion and that session may be said to have set the stage for the symposium this year at Atlantic City.

In the intervening years several things had happened, two of which will bear mentioning. The fact that the test on notched bars gives important information which the tensile test misses had become rather widely recognized among engineers and metallurgists, and the broader outlines of a sound theory of notch behavior had been developed. This was evident at the round table discussion and promoted the desire to have both aspects of "impact" testing considered again, though in a more formal fashion. We may say that the symposium presented this year will undoubtedly contribute to a more positive attitude in this country towards this class of tests. Two papers were also included on the testing of welds.

The symposium was sponsored jointly by the American Society for Testing Materials and the Welding Research Committee of the Engineering Foundation and was under the general direction of M. F. Sayre, professor of applied mechanics, Union College, Schenectady, N. Y., and W. W. Werring, Bell Telephone Laboratories, Inc., New York. They have rendered valuable service to the engineers of this country by bringing to them up-to-date discussions of both notched bar testing and impact testing. Your reporter cannot help but feel that better use might have been made of this opportunity to distinguish between notched bar tests and impact tests, and thus contribute to a much needed clarification. How are we ever going to get straight in our thinking if we persist in calling a test on a notched bar, an impact test, as though it related specifically to shock in service!

Utility Impact Testing

The first paper was "Utility Impact Testing" by Sam Tour, Lucius Pitkin, Inc. Without attempting to disparage the standard tests for brittleness, the speaker emphasized the value of tests of whole parts or structures and of test samples, rough shaped and incompletely fashioned, taken from such parts, in contrast to standard test bars taken from those parts and subjected to a standard test. Such tests he called "utility tests". On other occasions a finished machined test sample, but not of standard dimensions, may be used. This he called a "non-standard" test. The following examples were given of such tests which have proven of value in industry.

Fiber board is tested by a "drop impact testing machine" and the same test has been applied to other materials such as a vitreous enamel coating on metals. A test very similar to the Charpy test is used for wood, the test bar in this case being un-notched. In England the increment type of drop test is used for wood. Tests for concrete, stone, and enamel were similarly discussed.

Automobiles on proving grounds are tested by impact on a Belgium block pavement. Spring stock for coiled springs is given a non-standard test in full size with a 1/16-in. notch. Round bars of this type may be conveniently tested on the Izod machine. The teeth of gears are subjected to a drop impact test to bring out qualities of the steel which are not detected by tensile and hardness

tests. Cap screws are also tested on an impact machine and if the break comes at the head instead of through the threads, the head was improperly made or else the wrong steel was used. Pipe and tubing are also tested on the Izod machine. A pendulum type of test which is used in England for testing full sections of rails was described but nothing was given on the standard drop test which is used in this country.

Not all utility impact test problems have been solved, it appears, as witness the search for a substitute for glass in an airplane windshield which is required to pass a test which simulates the impact of a 4-lb. duck impinging at 60 miles per hour on an airplane which is traveling in the opposite direction at 200 miles per hour.

Impact Testing of Plastics

The second paper dealt with "The Impact Testing of Plastics", by R. Burns and W. W. Werring, Bell Telephone Laboratories, Inc. No one test is adequate for testing molded plastics but if a material passes a notched bar impact test, similar to the Charpy or Izod, an un-notched bar impact test, and a flexural test, it has been found that it stands up well in service. The former test was discussed at length and was shown in detail by means of high speed moving pictures. By illuminating the specimen with polarized light it was shown that a stress wave sweeps over the broken test bar immediately after breaking, presumably due to a spontaneous relief of stress.

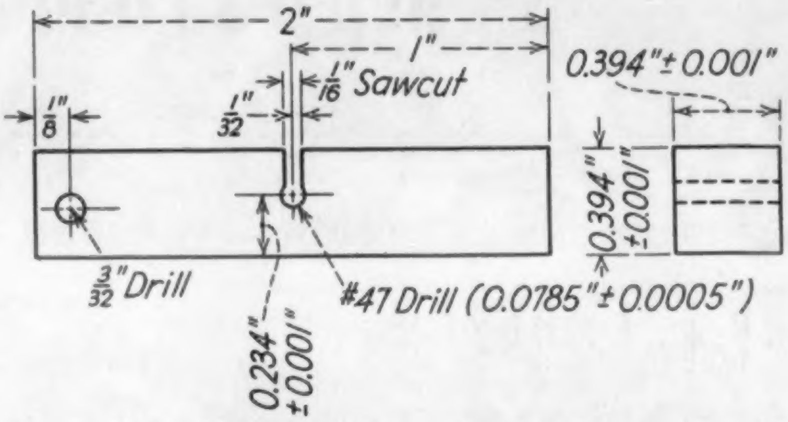
Notched-Bar Impact Test

The next paper featured that portion of the symposium which related to the practical use of the notched bar test. It was entitled "Practical Applications of the Notched-Bar Impact Test", by G. C. Riegel and F. F. Vaughn, Caterpillar Tractor Co. This paper drew on the authors' extensive experience in purchasing and processing steel and their use of the notched bar test as a guide. From this experience they drew the following conclusions.

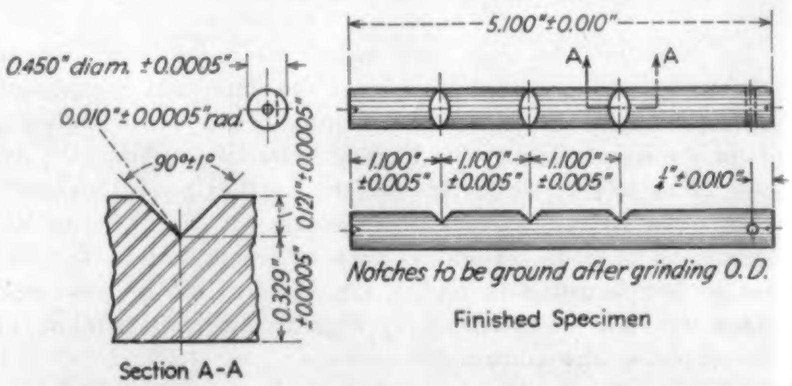
> No. 1. The notch-bar impact test is useful in evaluating the quality of ferrous metals, even though the material is not called upon to resist impact stresses in service.
>
> No. 2. The notched-bar impact test is a more discriminating proof of the quality of heat treatment of ferrous metals.
>
> No. 3. The notched-bar impact test predicts the behavior of ferrous metals under conditions which produce brittle cleavage.

This paper was of outstanding value in this symposium and at this time, for it gave the answer to what can be accomplished by the studied and persistent use of the notched bar test in the large scale manufacture of steel parts which are subjected to difficult service. If one were to attempt the same control by the sole means of chemical analysis and tests made on plain un-notched bars, he would avoid contact with one vital property—cohesive strength—which is frequently responsible for failure in service. It was pointed out that poor notched bar impact values can enter with the steel as purchased or through faulty heat treatment or via the incorrect choice of steel analysis. All three of these factors were discussed and illustrations given.

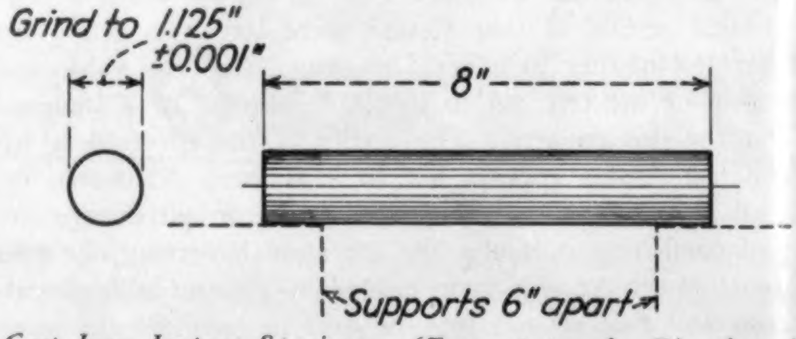
This paper was also notable in that it gave the first published description of the use of single and double width Charpy bars. The single width value at 7.5 ft.-lbs. was low enough to excite suspicion but when the double width value was found to be only 6.75 ft.-lbs.—other properties being satisfactory we may assume—the heat of steel was not accepted for the purpose intended. Considerable practical information on this type of testing was also given.



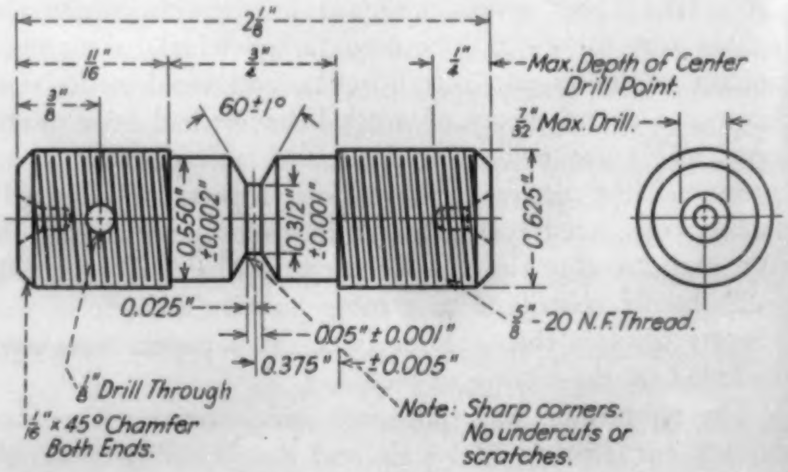
Charpy Type Impact Specimen. Saw cut must not strike side or bottom of drilled hole. (From paper by Riegel and Vaughan).



Izod Type Impact Specimen. (From Paper by Riegel and Vaughan).



Cast Iron Impact Specimen. (From paper by Riegel and Vaughan).



Notched Tension-Impact Specimen. (From paper by Riegel and Vaughan).

In the discussion it was pointed out that the authors stated that the notched bar test showed S.A.E. 2345 to be superior to 5150 for gears, with the service record in agreement with the laboratory tests. The question was asked how that could be in view of the finding of Almen and Boegehold that tooth shape, finish, and warpage were of more importance than the material of which the gear was made.

Your reporter understands that the two steels were put through the same shop procedure and that the gears contained no material differences. What is really significant is that in one case the failure was by fatigue or notch-fatigue and in the other by the sudden breakage of a whole tooth. The relatively low cohesive strength of the 5150 steel is brought out in test or in service only in case the failure or rupture is sudden and complete, as is suggested in conclusion No. 3.

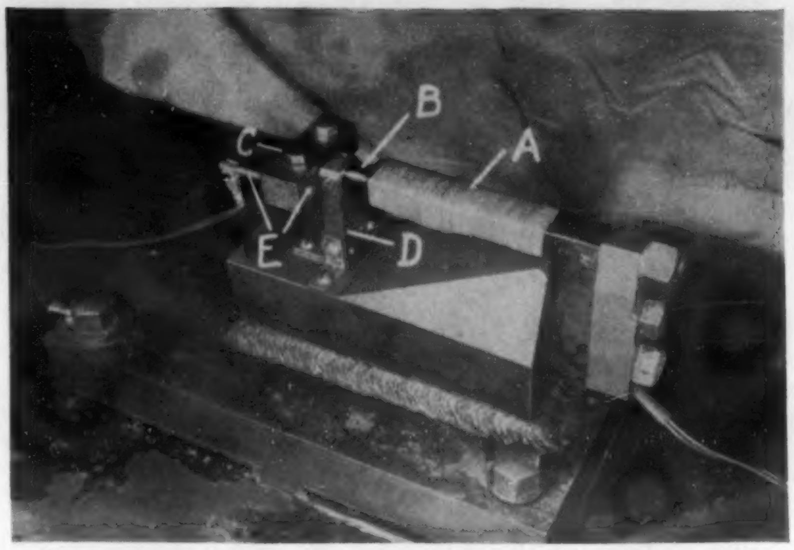
Charpy Test and Toughness Near Welds

The next paper was "The Use of the Charpy Test as a Method of Evaluating Toughness Adjacent to Welds", by W. H. Bruckner, University of Illinois. As stronger steels are used for welding, it is found that a hard and brittle zone occurs adjacent to the weld. This may require preheating the stock or may even eliminate the steel for welding purposes. This feature of welding was extensively studied by the author. The zone is too narrow to permit satisfactory tests and hence a "weld-quench" procedure was developed which reproduces closely the same grain size, structure, and hardness as the affected zone, when applied to a half size Charpy bar. With this test the various steels are readily classified according to "weldability", or into those which can be welded about the same as mild steel, those which require preheating, and those which are difficult or impossible to weld satisfactorily. This paper is very timely with the introduction of new high-strength structural steels, which of course inspired the investigation.

In the absence of a formal paper H. C. Mann described his work at the Watertown Arsenal on high velocity impact testing. In introducing his talk the speaker stated that he had not as yet found a correlation between the results of his test and service behavior. He then proceeded to a discussion of earlier work which is too well known to require review here.

Stress Strain Relations

The next paper also dealt with straight impact loading: "Stress-Strain Relations Under Tension Impact Loading", by D. S. Clark and G. Dätwyler, California Institute of Technology. The authors have been studying impact testing in their laboratories for several years and after considerable searching for a method they finally arrived at a new type of tension dynamometer with recording equipment. Test results are reported for several ferrous and non-ferrous metals which were obtained on a pendulum type of impact testing machine with a striking velocity of 11 ft. per sec. The maximum stress generated in impact varied from about equal that of static loading to 1.4 times, while the energy ratio varied from 0.6 to 2.8, though, aside from the specific data contributed, the paper is of value particularly for the description of a satisfactory test method.



Dynamometer. (From paper by Clark and Dätwyler).

The accuracy of the measuring devices was shown by comparing its results with the energy absorption determined at the same time by the pendulum and by measuring the actual elongation of the broken test bar. These checked with the "force-elongation" diagrams. There appears to be no good reason why this method cannot be employed for higher striking velocities and results from this laboratory will be awaited with great interest. Let us hope that sound engineering data will be made available for the many problems involving high velocity loading on metals.

Theory of Impact Testing

The next paper may be said to pair up with the one by Riegel and Vaughn, to present the theoretical side of impact testing as developed in the past 15 years. It was entitled "The Theory of Impact Testing: Influence of Temperature, Velocity of Deformation, and Form and Size of Specimen on Work of Deformation," presented by D. J. McAdam, Jr. and R. W. Clyne, of the Bureau of Standards and the American Steel Foundries, respectively.

This is an excellent and thoughtful review of the subject matter and also gives typical data which are pertinent to the important points involved in this field. A careful study of this paper would be well worth while for any body who is interested in going beneath the surface in

Recording Apparatus. (From paper by Clark and Dätwyler)

both notched bar and impact testing. The authors treat both fields from the common point of view of Ludwik's hypothesis and the work of Kuntze on cohesive strength. This is theoretically sound, for brittle fracture occurs whenever the deformation of the metal is accompanied by a tensile stress that overcomes the cohesive strength, whether that be due to the notch effect or velocity of deformation, but the stress conditions imposed by these two variables are actually so different that it seems desirable to treat them separately.

In this connection, for example, if we clarify these ideas we would avoid the following ambiguous statement of the authors' that "An impact test should not be viewed as a simulation of shock in service". It would appear that the time is ripe, particularly with this paper before us, to select and define terms for use in this field.

A communication was received from N. Davidenkow entitled "Some Considerations on the Impact-Testing Problem", too late for printing. The feature of this discussion was the suggestion that the temperature at which a steel changes from ductile to brittle behavior be determined and that the difference between the operating temperature and it, divided by the operating temperature in degrees absolute, be used as a factor of safety by which to judge the steel in that application.

Impact Tests of Welded Joints

The next to the last paper again dealt with welding: "Impact Tests of Welded Joints", by W. Spraragen and G. E. Claussen, Welding Research Committee of the Engineering Foundation. The art of welding, the application of welding in engineering work, and the literature which covers both aspects, are growing fast. Among the valuable contributions of the Welding Research Committee are the reviews of the pertinent literature which are brought out from time to time.

The present review covers the period of January 1, 1936, to January 1, 1938, and reproduces the findings of 171 articles. It emphasizes the extensive application of notched bar testing and its ability to bring out good and bad qualities of weld metal and affected stock. One point that should be broadcast is contained in the following quotation:

> There are still those who are skeptical about welding and regard the heat affected zone as necessarily brittle in any steel. Tests have shown the zone to have ample low-temperature Charpy values even in base metal that is brittle in the Charpy test at low temperature.

Your reporter has learned that a layman regards a photograph of this heat affected zone with dire suspicion. He is capable of taking a lot on faith but he feels instinctively that the part is bound to break off sharply where the affected zone meets the unaffected stock. The effects of nitrogen and oxygen are dealt with at some length but here it is unfortunate that the welding conditions and type of weldrod are not given more specifically. It would be worth while knowing if it is the gas producing rod of the Smith-Stresau type or the heavy mineral coated type or some combination of the two that is being discussed. Furthermore the total gas percentage is used invariably though it is known that the form in which each of these elements occurs is the point of real significance and vital to the effect on the weld metal. This also applies to the effect of heat treatment and of multi-pass welding. Many important points are covered by this review, too numerous to discuss here, while considerable progress is shown by the account of tests of welded structures.

A Summary and Comments

The final paper was "Notched Bar Testing and Impact Testing: A Summary", by S. L. Hoyt, A. O. Smith Corp. This was an attempt to clarify both fields of testing, to show what the present position is and what is not yet understood, and to indicate the outlines of a rational testing procedure.

The Ludwik theory, which guides both fields, leads to the important conclusion that the data of real significance in judging metal quality relate to those conditions which cause a metal to change from ductile to brittle behavior. (A corollary of this shows that the absolute values of energy absorption in the notched bar type of test should be accorded much less significance.) This leads to a division of the variables which bring that about into two groups, first temperature and striking velocity and second the geometry of the part. The significance of this grouping is discussed in the paper while it is also shown that these factors must be included in the tests of notch, temperature, and velocity sensitivity to secure an adequate understanding of metal quality or of service behavior.

Our present tests, both here and abroad, do not now take this into account, presumably to keep testing conditions simple and avoid the use of temperatures other than room temperature. In particular a procedure for testing steel for notch sensitivity (at one temperature and one striking velocity) is discussed. It is based on the "matching" principle which, for practical reasons, is abbreviated to the use of single and double width or triple width test bars.

The field of impact testing is discussed on the basis of the classical work of Considére which brought out the effects of striking velocity and temperature. There is great need for an extension and amplification of that early work but it still gives us the best picture of the principles. The more recent work of Mann was also discussed to show that his representation of impact behavior, particularly the slow drop in impact value with increased elongations above the "transition velocity", is directly opposed to both theory and practice.

SIGNIFICANCE OF THE TERMS

Troostite and Sorbite

by J. R. Vilella and L. R. Cooper

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In view of the questionnaire sent out by Prof. Sauveur, the replies to which are appended to this article, it seemed desirable to have a concise re-statement of the actual subject under discussion. We have a suspicion that some of the replies were made on the basis of a not too clear recollection of what the discussion is really about.—H.W.G.

SINCE 1912 THE REPORT of Committee 53 of the International Association for Testing Materials[1] has been the standard for the nomenclature and definitions of the structures of steel. In the meantime new knowledge pertaining to the structures of steel has been acquired, the methods of preparing specimens for microscopic examination have been improved, and the visual range of metallurgists has been extended by microscopes of improved design and objectives of higher resolving power. In consequence of this progress, an increasingly large number of metallurgists have in recent years departed from the Committee's nomenclature in an endeavor to describe their observations more precisely. This has, inevitably, caused some controversy and confusion. It is not surprising, therefore, that a desire should exist today for a system in which all names mean the same to everybody, and in which the precise meaning and connotations of the terms are in accord with modern views.

The Committee's report is in effect based on the view that the transformation of austenite to pearlite occurs in a series of steps or stages. According to this view, when austenite is cooled to a temperature below the A_{1E} it transforms first to martensite, but martensite being unstable, transforms immediately to troostite, which in turn changes to sorbite, which finally coagulates into lamellar pearlite. If the cooling rate is sufficiently rapid, the transformation is denied time to proceed beyond the first stage and the resulting structure is martensite; but if it is less rapid, the transformation is arrested in the second or third stage and the resulting structure is, respectively, either troostite or sorbite. To reach the pearlite stage the transformation must proceed at a rate sufficiently slow to allow time for the coagulation of this sorbite into the relatively coarser lamellar arrangement typical of pearlite. On this view the cooling rate can be such as to produce intermediate stages such as troostito-sorbite, sorbito-pearlite and possibly, although not specifically mentioned in the report, martensito-troostite.

Some Definitions

In conformity with this theory the structures of steel were defined as follows:

Martensite: The early stage in the transformation of austenite characterized by needle structure and great hardness, as in hardened high carbon steel.

Troostite: In the transformation of austenite the stage following martensite and preceding sorbite (and osmondite if this stage is recognized).

Sorbite: In the transformation of austenite, the stage following troostite and osmondite, if this stage is recognized, and preceding pearlite.

Pearlite: The iron carbon eutectoid, consisting of alternate masses of ferrite and cementite.

From this concept of the transformation of austenite, it follows logically and is so stated in the report of the Committee on Nomenclature, that a steel made martensitic by rapid cooling, i.e., the transformation arrested in the first stage, can be advanced to the second or troostite stage "by reheating to slightly below 400 deg. C" and to the third or sorbite stage "by reheating to a little above 400 deg. C, but not to 700 deg. C at which temperature it coagulates into granular pearlite". Moreover "with slightly further reheating it (troostite) changes into sorbite; with higher heating into sorbitic pearlite and then slowly into granular pearlite and probably indirectly into lamellar pearlite". It may be noted that this statement seems to be inconsistent with the earlier statement that tempered sor-

bite always changes to *granular* pearlite. It is difficult to understand how it is possible to obtain *lamellar* pearlite by tempering troostite, if the transformation must go first through the stage of tempered sorbite.

The first implication following logically from this concept of the transformation of austenite is that *exactly* the same structures, sorbite, troostite and "indirectly" lamellar pearlite, are formed by the decomposition of austenite on cooling and by the decomposition of martensite on heating. That this is not true, is generally recognized today. Any trained observer with access to a good microscope can see that the structures resulting from cooling austenite at a rate less than that required to produce martensite constitute an unbroken series of *lamellar* structures whose fineness increases continuously with the cooling rate (Figs. 1 to 4), whereas those resulting from reheating martensite form a series of *granular* structures in which the coarseness of the carbide particles increases continuously with the heating temperature and the duration of the heating treatment (Figs. 5 to 8). It is known, moreover, that members of these two series of identical hardness differ in some other properties, and thus must be regarded as unlike[2].

The second implication of the transformation-by-stages theory is that the series of lamellar structures resulting directly from the transformation of austenite and the series of granular structures obtained by reheating martensite each exhibit discontinuities which permit the observer to detect, for example, where troostite ends and sorbite begins. In spite of a diligent search, and of the most careful technique, we have been unable to detect any identifiable breaks in these series.

How to Produce the Structures

The report of the Committee not only names and defines the structures but it also gives their constitution and description and tells how they may be made. It is of interest to see how the 1912 concepts of the constitution of sorbite and troostite fit with the structures obtained by actually carrying out the instructions given to prepare them.

Let us consider troostite first, the constitution and composition of which are stated as follows: "An uncoagulated conglomerate of the transition stages. The degree of completeness of the transformation represented by it is not definitely known and probably varies widely."

In everyday metallurgical language this presumably means that troostite is considered not as a definite structure, but an ill-defined mixture of martensite, osmondite (if this stage is recognized) and sorbite in varying proportions. This conglomerate "arises (1) on reheating hardened (e.g. martensite) steel to slightly below 400 deg. C, or (2) cooling through the transformation range at intermediate rate, e.g. in small pieces of steel (a) quenched in oil, or (b) quenched in water from the middle of the transformation range or (c) in the middle of larger pieces quenched in water from above the transformation range". In order to see for ourselves what the structures which they contemplated actually looked like, we followed their instructions as precisely as possible and prepared the series of photomicrographs which we now proceed to discuss.

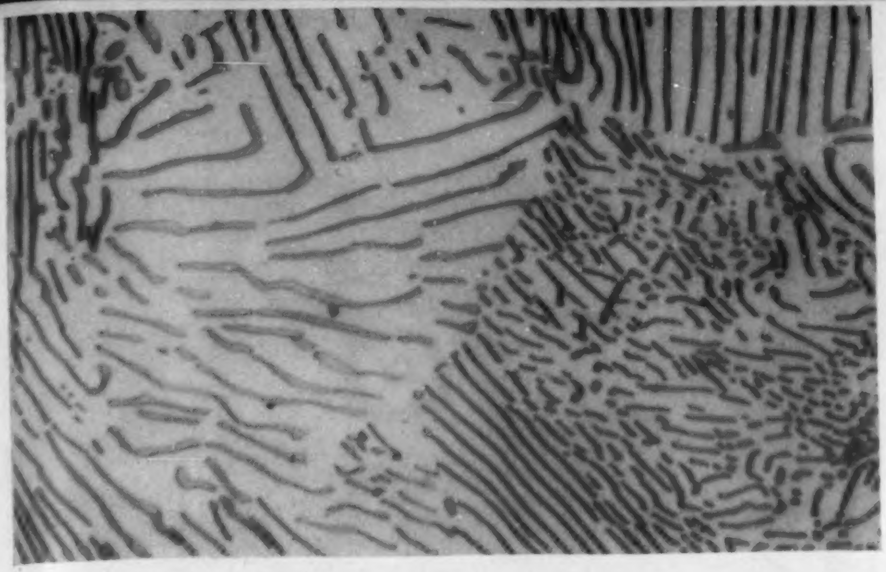
The structures obtained by carrying out recommendations (1) and (2a) are shown in Figs. 8 and 4 respectively. The difference between these two types of structure was discussed previously. The structure obtained by following (2b), quenching in water a small piece of 0.35 per cent carbon steel from approximately the middle of its transformation range, (Ac_3 — 1475°F, Ac_1 — 1345°F, quenching temperature—1410°F) is illustrated in Fig. 9. A hypoeutectoid steel was chosen for this experiment, because if there is a transformation *range* in eutectoid steel, it is so narrow as to make it extremely difficult, with present day equipment, first to ascertain and then to heat treat at its middle temperature. The structure is a mixture of martensite and ferrite precisely as is expected from a proper interpretation of the iron-carbon equilibrium diagram. Indeed it is difficult now to understand how anything different could have been expected, since within the transformation range austenite and ferrite coexist, so that quenching a sufficiently small piece in water under these conditions can only produce martensite and ferrite. Fig. 10 shows the structure at the middle of a 1-in. diameter specimen of 0.58 per cent carbon steel quenched in water, following instruction (2c); its appearance is that of a fine, partly unresolved, but distinctly lamellar pearlite.

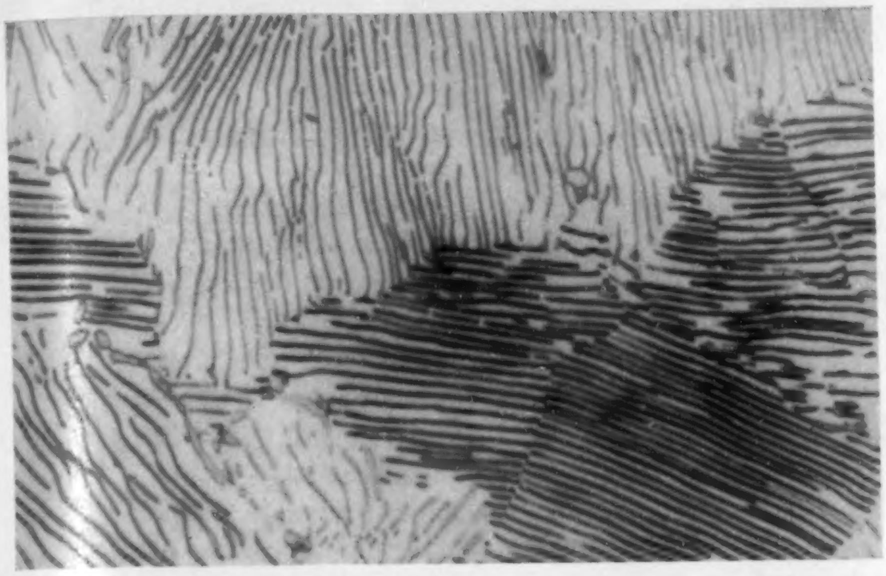
Constitution of Sorbite

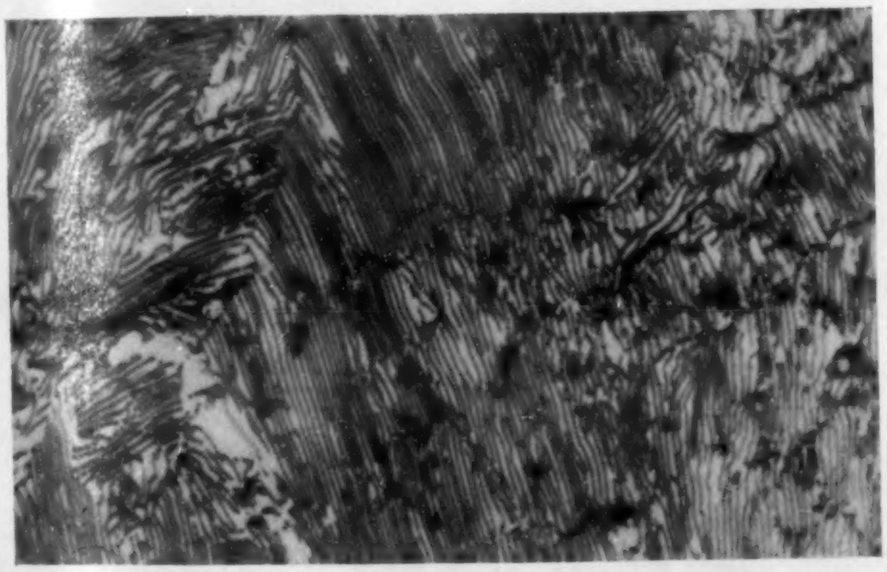
Let us now turn our attention to the constitution of sorbite, and to the various ways in which it can be made. The Report states:

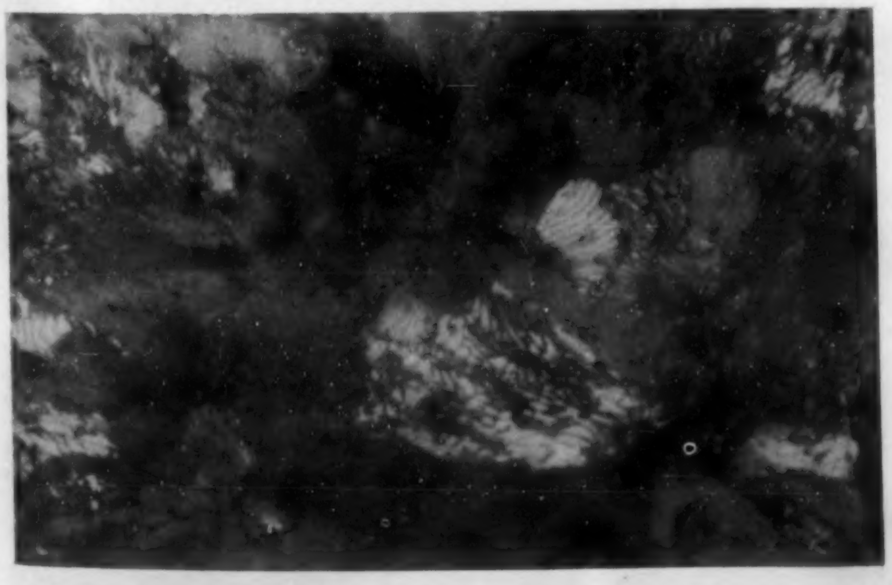
"*Constitution and Composition:* Most writers believe that it is essentially an uncoagulated conglomerate of irresoluble pearlite with ferrite in hypo- and cementite in hyper-eutectoid steels respectively, but that it often contains some incompletely transformed matter." The first question raised by this statement is, exactly what is meant by "incompletely transformed matter"? "Matter" must mean austenite, for austenite is the only thing transforming; yet we have already been told that incompletely transformed austenite is either martensite, troostite, osmondite (if this stage is recognized) or sorbite. Thus it appears that sorbite may be an indefinite mixture of one or more of these transition stages with "irresoluble pearlite" plus either ferrite or cementite depending on whether the steel is hypo- or hyper-eutectoid. Possibly something less complex was meant, but exactly what cannot be inferred from their statement.

In trying to visualize their conception of sorbite, one is led to think that it hinges on the meaning attached to "irresoluble". It seems clear that by "irresoluble" was meant *not resolvable even at the highest power of the microscope,* for otherwise the numerical aperture of the objective and the magnification would have been specified. It is hardly conceivable that the committee could have meant that the structure of a piece of eutectoid steel air cooled from, say 1500 deg. F, should be *sorbite* if examined at 100 dia. because the structure was not resolved at that magnification, but is *pearlite* when resolved at 500 dia. with the aid of a more powerful objective. The fact that no magnification or numerical aperture was specified is indicative of the intention of reserving the term sorbite (and troostite) for those structures whose lamellae they could not see at any magnification. The conclusion is unavoidable, therefore, that the concept of sorbite arose largely from the inability of the microscopes then available to render visible the true configuration of the structure, and not from positive microscopic evidence.

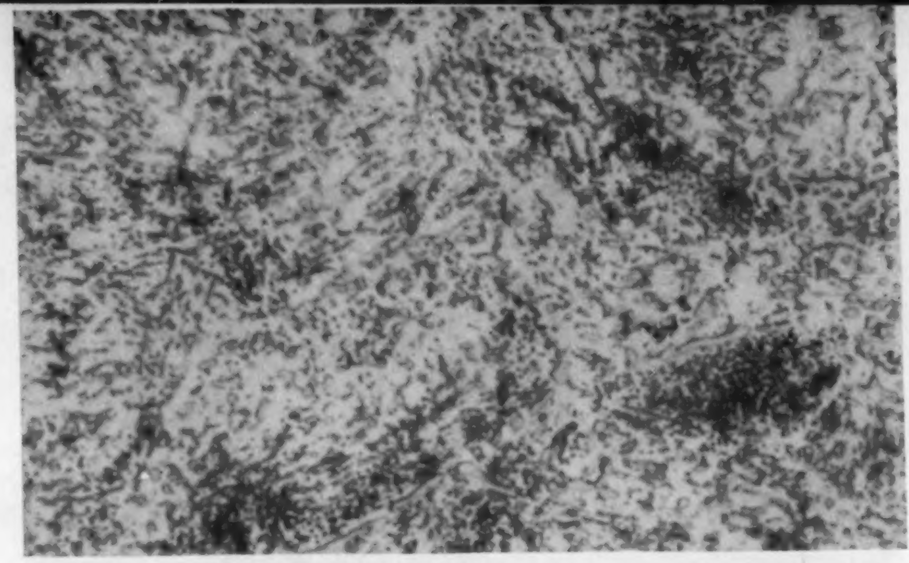


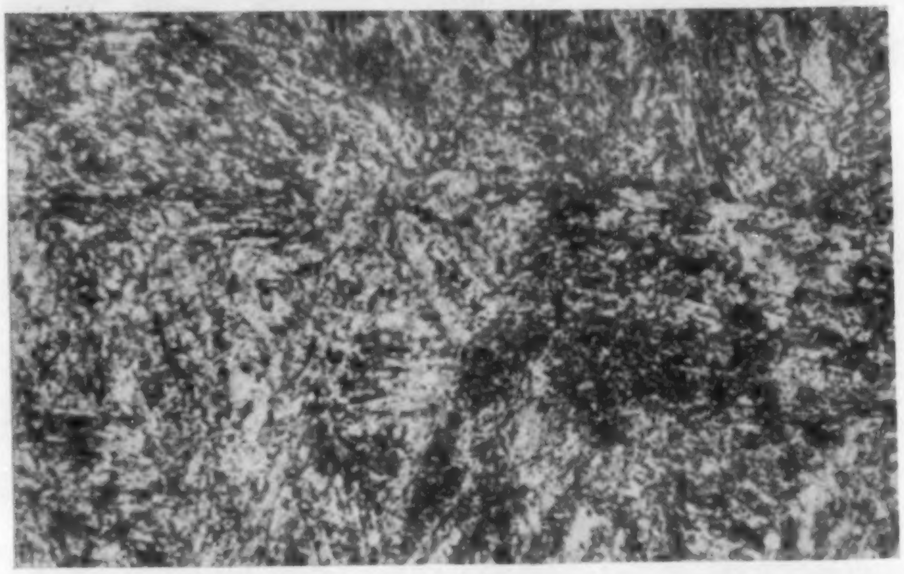


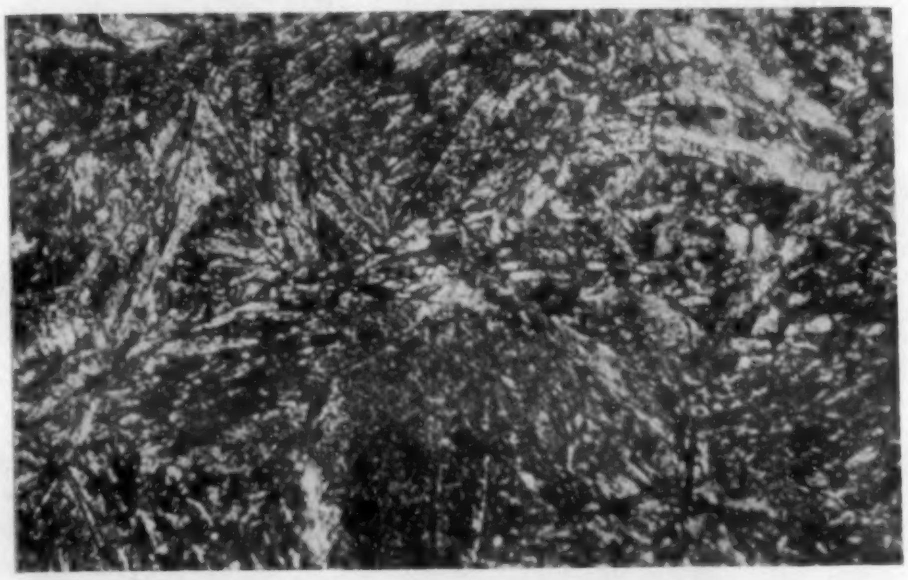


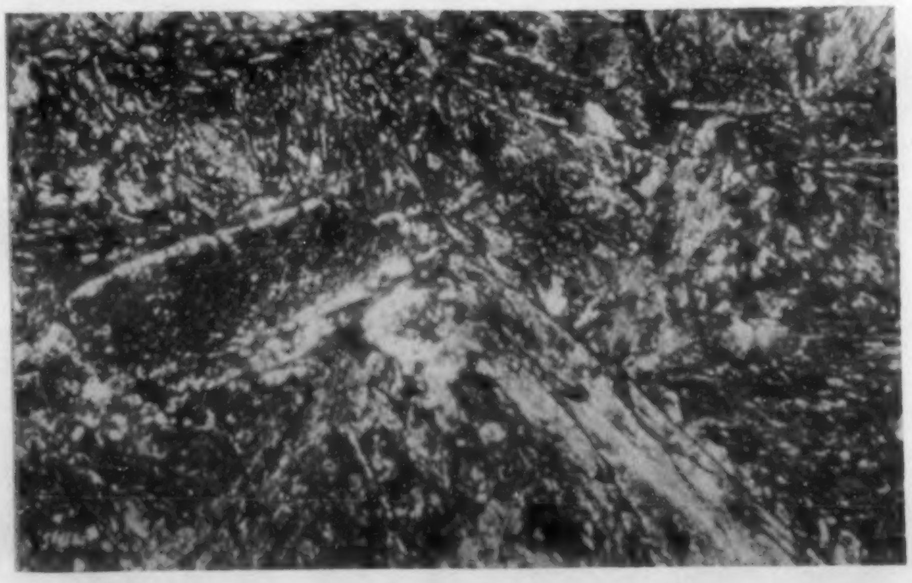


Lamellar Type of Structure. X 2000. 0.89 per cent C—cooled from 1600 deg. F. as follows: Fig. 1 (Top)—Furnace cooled; 1 deg. F. per min. Fig. 2—Furnace cooled; 5 deg. F. per min. Fig. 3—Air cooled; 300 deg. F. per min. Fig. 4—Oil quenched: more than 6000 deg. F. per min.









Granular Type of Structure. X 2000. Same steel, water quenched from 1600 deg. F. and tempered 1 hr. at the following temperatures: Fig. 5 (Top) 650 deg. C. (1200 deg. F.) Fig. 6—550 deg. C. (1020 deg. F.) Fig. 7—450 deg. C. (840 deg. F.) Fig. 8—350 deg. C. (660 deg. F.)

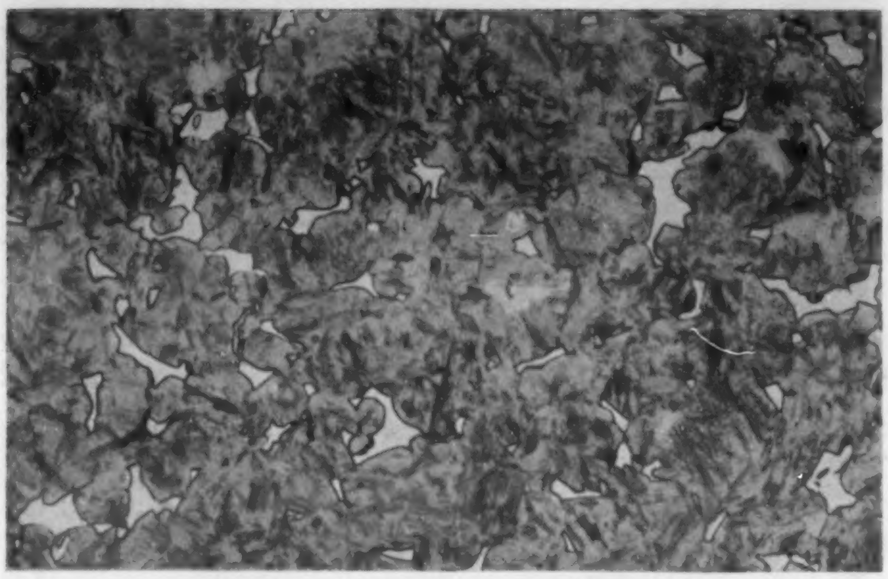


Fig. 9—C Steel, 0.35 Per Cent, Water Quenched from Middle of Transformation Range—1410 deg. F. X 500.

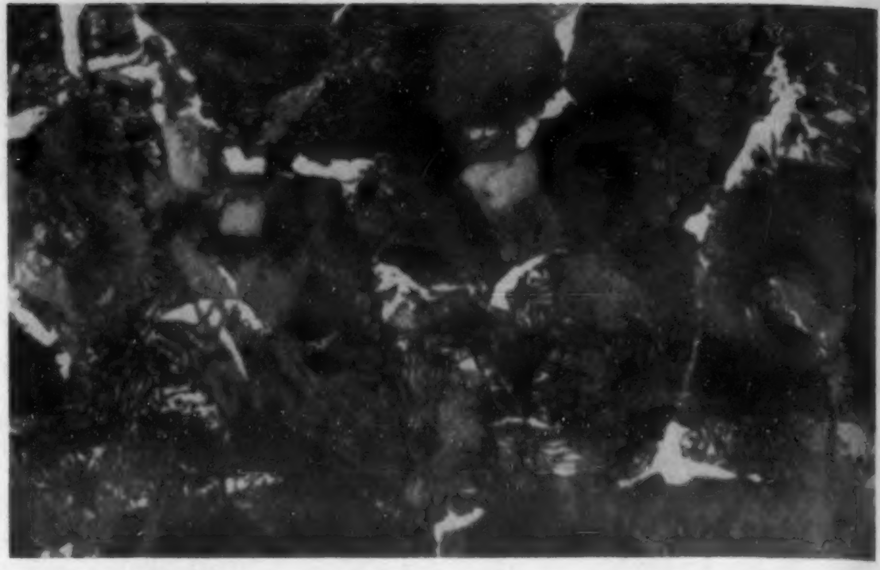


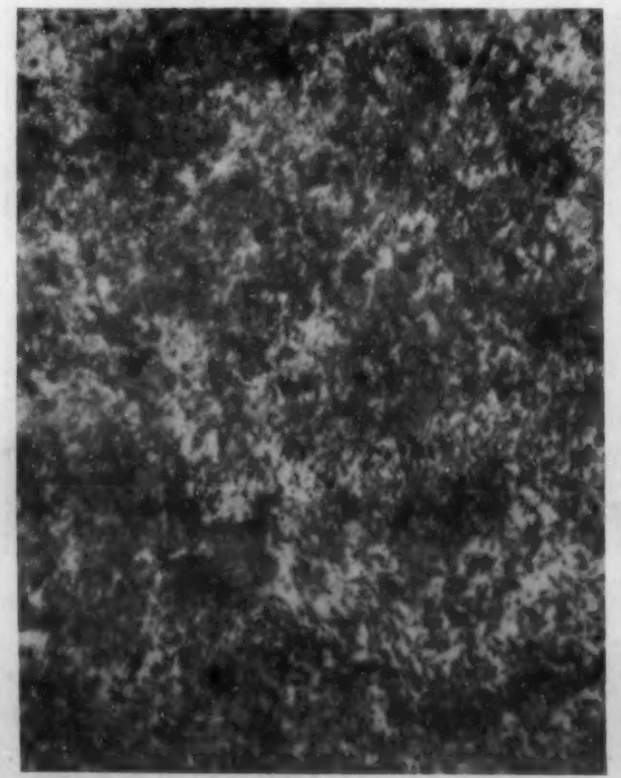
Fig. 10—C Steel, 0.58 Per Cent, Water Quenched from 1500 deg. F. Area at center of 1-in. cylindrical specimen. X 2000.

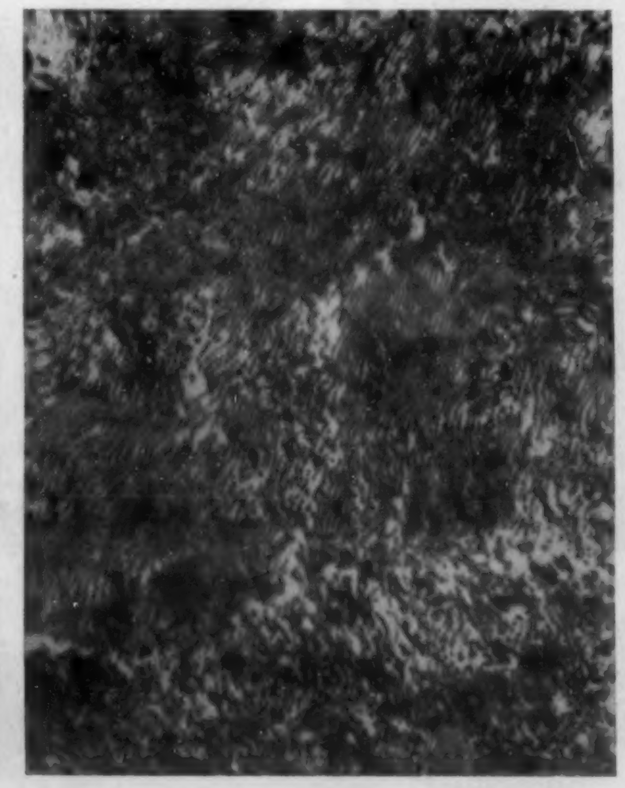
Effect of Polishing and Etching Methods

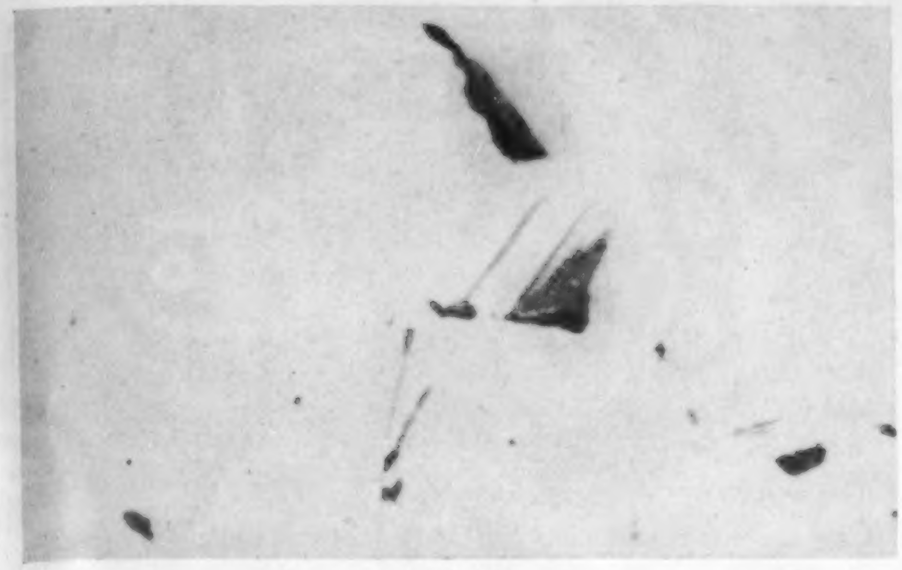
It is not improbable that the methods of polishing and etching practiced at the time also contributed toward their concept of troostite and sorbite. As an illustration of how this could have happened consider Fig. 11. From its appearance it may properly be called either troostite or sorbite, for the phrase "irresoluble uncoagulated conglomerate" describes it very well. It etches rapidly and cannot be resolved into well defined lamellae at any magnification. Yet, this structure is no more than a case of distortion of the surface metal brought about by polishing. Figs. 12 and 13 represent exactly the same field, photographed at the same magnification with the same objective and ocular, after partial and complete removal of the distorted surface metal. This illustration is by no means an exaggerated case; similarly distorted structures, generally called "sorbite", are not infrequent in the literature today.

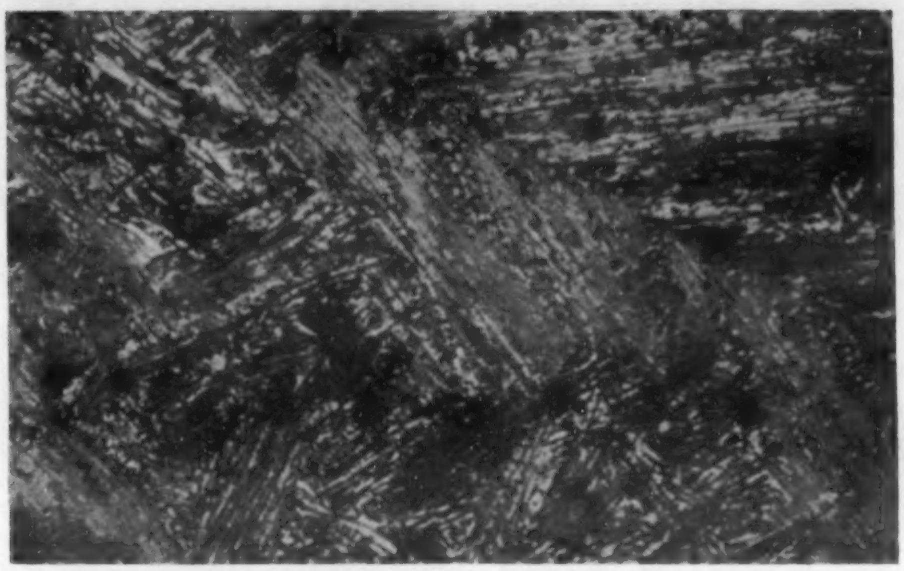
One cannot help but feel that had the metallurgical microscopes and polishing technique been as well developed then as they are today, the difference between the series of structures arising from the direct transformation of austenite and those produced by tempering martensite would have been accorded a greater significance, and a different system of nomenclature would have been evolved. What sound reason would there have been for giving three names to a continuous series of *lamellar* structures and at the same time giving two of these names (troostite and sorbite) to another continuous series of *granular* structures? What sound reason exists today for perpetuating this confusion?

Effect of Polishing on Appearance of Structure. X 1000. Fig. 11 (Left)—Appearance of structure after polishing and etching; shows distorted surface metal. Fig. 12—Same field after repolishing and re-etching. Distorted metal partially removed. Fig. 13—Same field after repolishing and re-etching a second time. The complete removal of the distorted surface metal discloses the true structure of the steel.









Structures Resulting from Quenching in Molten Lead (Bainite). Fig. 14 (Left)—Eutectoid steel quenched from 1650 deg. F. into molten lead at 850 deg. F. and held at that temperature for 5 secs. X 1000. Fig. 15—Same steel, similarly quenched but held in molten lead for 28 mins. X 2000.

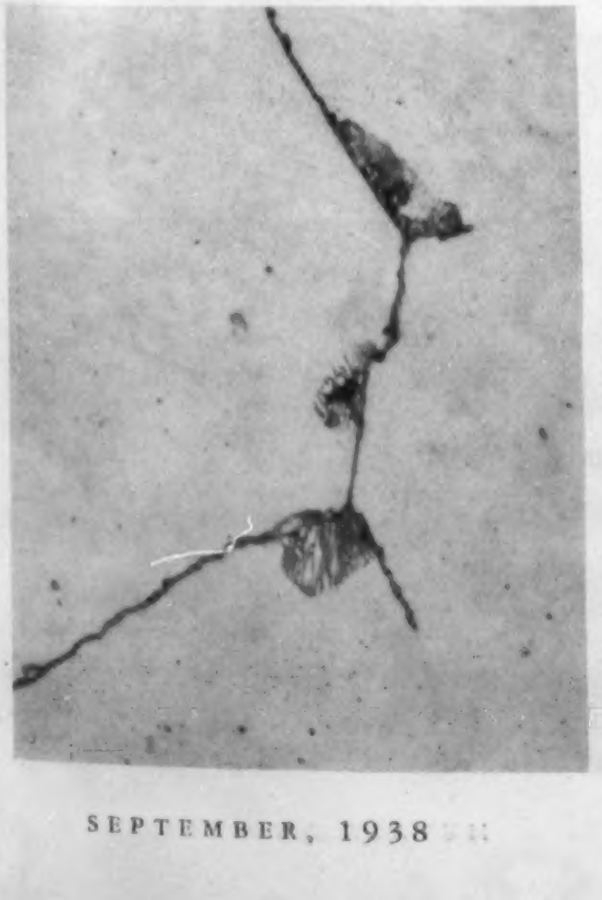
The Heat Treatments

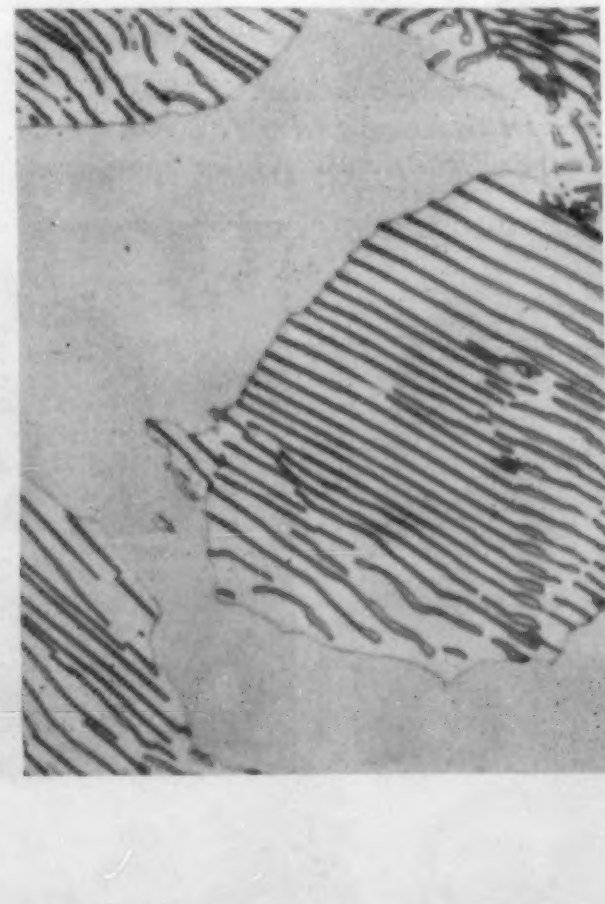
Turning our attention now to the heat treatments described under the heading "Occurrence" of sorbite, we find the following: "The transformation can be brought to the sorbitic stage (1) by reheating hardened steel to a little above 400 deg. C. but not 700 deg. C. at which temperature it coagulates into granular pearlite; (2) by quenching small pieces of steel (a) in oil, (b) or in molten lead (c) or even by air cooling them; (3) by quenching in water from just above the bottom of the transformation range, Ar_1." (It is to be emphasized that Ar_1, "the bottom of the transformation range", is not a definite temperature characteristic of a given steel, and is properly applied only to a given specimen previously cooled in a specified manner. Its use has resulted in considerable confusion.)

Each of these methods was carried out, and representative photomicrographs of the structures so produced are included. The results of treatments (1), (2a) and (2c) are shown in Figs. 7, 4 and 19, and 3 respectively. Since oil quenching of a small piece is given as a method for making both troostite and sorbite, Fig. 4 serves a dual purpose. Figs. 5 and 6 also show sorbite made by tempering martensite above 400 deg. C. but below 700 deg. C.

In following instruction (2b) by quenching in molten lead, the temperature of the bath and the time that the specimen was to be held in the bath had to be decided in advance. Inasmuch as both factors are significant, five combinations of different temperatures and times were tried. Figs. 14 and 15[3] show the structures obtained by quenching in molten lead at 850 deg. F. and holding it at that temperature for 5 secs. and 28 min. respectively; Figs. 16, 17 and 18[3] those obtained from the same steel quenched in lead at 1325 deg. F. and held at temperature

Structures Resulting from Quenching in Molten Lead (Pearlite). Fig. 16 (Left)—Eutectoid steel quenched in molten lead at 1325 deg. F. and held at that temperature for 2 mins. X 1000. Fig. 17—Similar steel quenched from 1625 deg. F. into molten lead at 1300 deg. F. and held at that temperature for 22 mins. X 2500. Fig. 18—Faster reacting eutectoid steel, quenched from 1650 deg. F. into molten lead at 1325 deg. F. and held at that temperature for 2 hrs. X 1000.





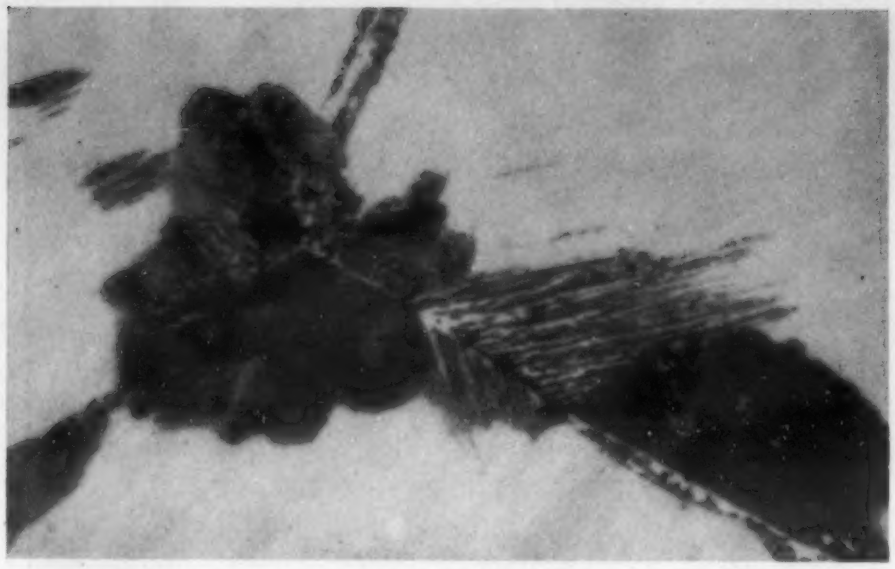


Fig. 19—C Steel, 0.68 Per Cent, Heated to 2100 deg. F., Cooled to 1500 deg. F. and Quenched in Oil. X 2000. (Compare with Fig. 4)

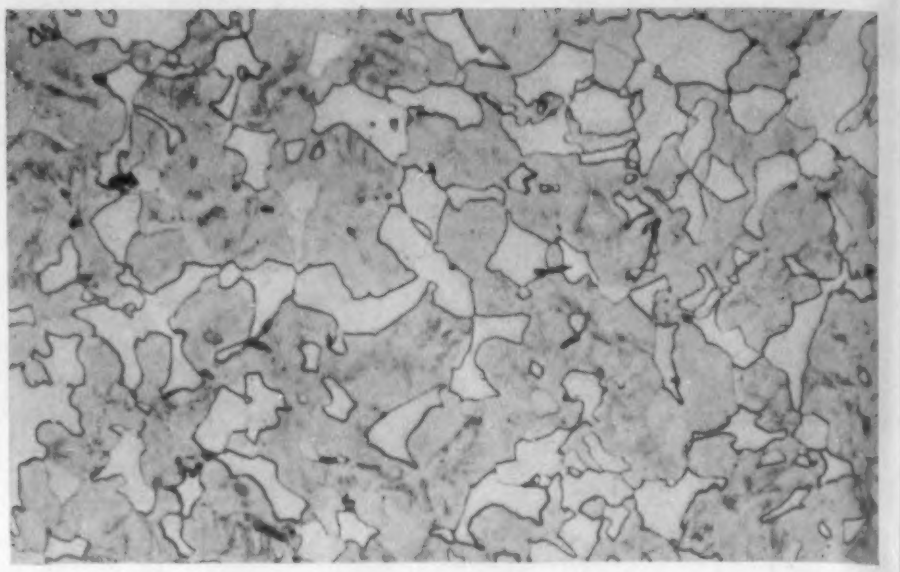


Fig. 20—C Steel, 0.35 Per Cent, Quenched in Water from Just Above Ac_1 (1365 deg. F.). X 500. (Compare with Fig. 9)

for 2 min., 22 min., and 2 hrs. respectively. None of these structures may properly be called sorbite; in fact, it was known in advance that nothing resembling sorbite is obtainable at the temperatures and times selected, for the steel used had been investigated previously by this method. Nevertheless the experiment was carried out for the sake of completeness and to illustrate another point which will be discussed presently.

Fig. 20 illustrates a piece of 0.35 per cent carbon steel quenched in water from the bottom of the transformation range (1365 deg. F.) according to instruction (3). The results are as expected from consideration of the iron-carbon equilibrium diagram, and nothing more need be added. (Compare Fig. 9).

Returning to Figs. 16 and 17, note the absence of any evidence of a "transition stage" at the interface of the pearlite and "austenite" areas. (It must be borne in mind, in interpreting these photomicrographs, that the martensite background represents the part of the structure which was austenite at the instant of quenching.) If the transformation occurred in stages, the chance of retaining at least some evidence of either sorbite or troostite was optimum in this experiment, for the austenite was in the act of transforming at the instant when the specimen ($\frac{1}{8}$x$\frac{1}{4}$x$\frac{1}{2}$ in.) was drastically quenched in brine. As a matter of fact there never was any experimental evidence for the assumption of transformation-by-stages.

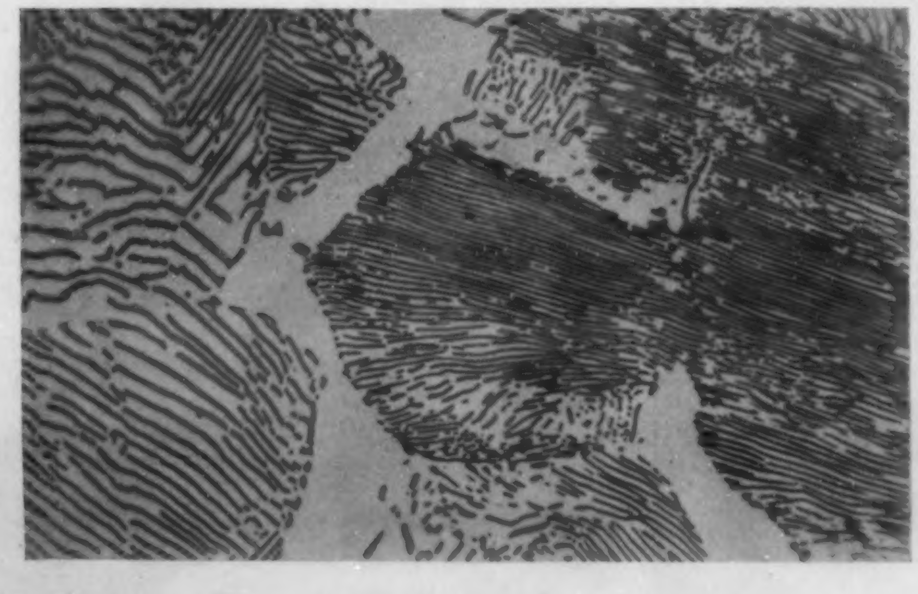
A Proper System of Names

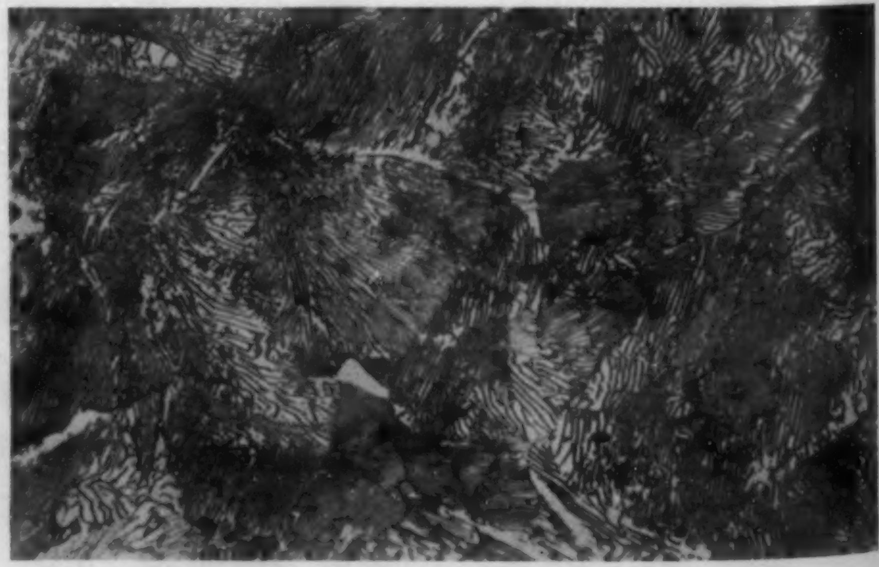
It is hardly necessary to dwell longer on the inconsistencies and ambiguities in the work on which is founded the present nomenclature. A more important question is, what, in the light of present knowledge, is the minimum revision needed to arrive at a logical, simple and adequate system of nomenclature?

A proper system of names, should, in our opinion, be in accord with the following general principles:

1. A name should be used to designate only a single type of structure.
2. The name should be based not on any assumption of the mechanism of formation of the structure, but solely on its appearance as disclosed by good metallographic technique without reference to carbon content or general composition of the steel.
3. A continuous series of structures—for example, as obtained by tempering martensite—should not be given more than one name unless there is some definitive landmark which does not depend upon the equipment and technique of the observer.

Pearlite Areas of Eutectoid and Less than Eutectoid Composition. X 1200. Fig. 21 (Left)—0.60 per cent C steel, furnace cooled from 1600 deg. F. Pearlite areas of eutectoid composition (0.80-0.85% C). Fig. 22—Same steel, $\frac{1}{8}$-in. specimen air cooled from 1600 deg. F. Pearlite areas contain approximately 0.65 per cent C.





There is probably more than one way of arriving at a system in accord with these principles. We make some suggestions which are believed (1) to be consistent with observed facts, (2) not to be based on any assumed mechanism or likely to be affected by future improvements in microscopy, (3) to be unequivocal and simpler than at present and (4) to involve a minimum of revision. These suggestions follow:

1. The name "Pearlite" should embrace all "pearly" or lamellar structures resulting directly from the transformation of austenite, irrespective of the fineness of the lamellae and of the carbon content of the individual pearlite area. For example, the structures shown in Figs. 21 and 22 would both be called "pearlite" even though the carbon content of the individual pearlite area is 0.80 to .90 per cent in Fig. 21 and approximately 0.65 per cent in Fig. 22. (Both structures were obtained from the same 0.60 per cent carbon steel; Fig. 21 by furnace cooling a ½-in. cubic specimen and Fig. 22 by air cooling a ¼ x ⅛ x ½-in. section, both from 1600 deg. F.)

2. The name "Sorbite" should be used to designate only the granular structures (as in Figs. 5 to 8) obtained by tempering martensite, irrespective of the carbon content of the steel, the rate of etching and size of the individual carbide granule. This type of structure is by many called "tempered martensite," and it is possible that this adequate and descriptive name may persist even if "Sorbite," for historical reasons, is formally adopted. Inasmuch as granular structures can also be made by *extremely* slow cooling from austenite, as well as by heating pearlitic steels to temperatures below A_{1E}, some may deem it advisable to distinguish these granular structures from those obtained by tempering martensite even though their appearance and properties are nearly identical. If differentiation should be desired, the name "Spheroidite" is suggested as a contraction of the phrase "spheroidized cementite." Today this latter expression is used to designate all coarse spheroidal structures, regardless of whether they arise from tempering martensite, from a subcritical anneal of pearlite, or from very slowly cooled austenite. While in many respects this is satisfactory, a name connoting that the structure did not arise from martensite may prove convenient.

3. The name "Troostite" is not really needed but, since it has long been used to designate the dark etching, nodular, finely laminated pearlite (Fig. 23) obtained by cooling steel at a rate just short of that required to make the structure 100 per cent martensitic, its retention to designate just that structure may be considered advisable by some. If the name Troostite is retained, it should be made clear that it does not imply a discontinuity in the lamellar series. The name should not be used for any portion of the granular series.

4. As a result of the work of Bain and Davenport on the transformation of austenite at constant temperature, a new series of structures was discovered. These differ from pearlite and tempered martensite in properties, appearance and mode of formation. Since plain carbon austenite cannot be transformed completely to these structures by any uninterrupted cooling rate, they are seldom observed in steel heat-treated by the ordinary methods. However, by careful polishing and etching, traces of this structure may sometimes be observed in steels incompletely hardened by water quenching, as is illustrated in Fig. 19. To these structures the name "Bainite" was tentatively given by his co-workers.[4]

The foregoing discussion of the Report of the Committee on Nomenclature may be regarded by some as a criticism of something long forgotten and out of date. Yet, the fact remains that this report and its underlying assumptions are the basis of the present nomenclature.

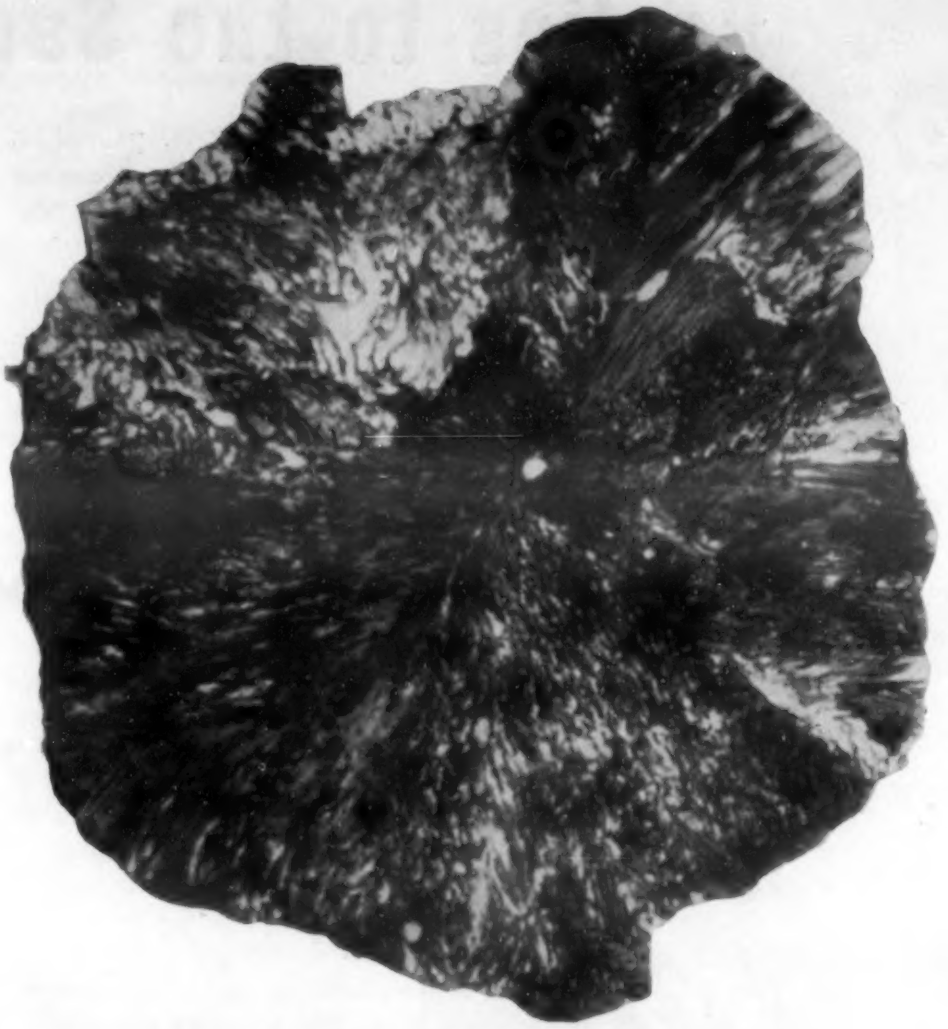


Fig. 23—Showing Lamellar Structure of So-Called "Nodular Troostite". X 2500.

Any effort to perpetuate the use of the terms "sorbite" and "troostite" to denote some indefinite subdivision of the lamellar series of structures is a tacit admission of the reality of discontinuities in the structures of steel for which there is no positive metallurgical or microscopic evidence. Likewise, the use of these two terms to denote both granular and lamellar structures implies identity when there is in fact real difference.

The points emphasized in the foregoing pages should, we submit, be borne in mind if a satisfactory system of nomenclature, consonant with present day knowledge of the structures occurring in steels, is to be attained.

The authors gratefully acknowledge valuable help received from H. A. Brown in the preparation of the specimens used for this article.

Notes

1. "On the Nomenclature of the Microscopic Substances and Structures of Steel and Cast Iron". Committee 53 was constituted as follows: *Chairman*, Prof. H. M. Howe; *Secretary*, Prof. Albert Sauveur; *Members*, Dr. F. Osmond, Paris; Dr. H. C. D. Carpenter, Manchester; Prof. W. Campbell, New York; Prof. C. Benedicks, Stockholm; Prof. F. Wust, Aachen; Prof. A. Stansfield, Montreal; Dr. J. E. Stead, Middlesbrough; Prof. L. Guillet, Paris; Prof. E. Heyn, Berlin-Lichterfelde; Dr. W. Rosenhain, Teddington. The text of this report may be found in "The Metallography and Heat Treatment of Iron and Steel", Albert Sauveur, 2nd Edition, 1920, page 460. Also in "Microscopic Analysis of Metal", F. Osmond and J. E. Stead, 3rd Edition, 1924, page 287.

2. For a more detailed discussion of the lamellar and granular series see "On Naming the Aggregate Constituents in Steel" by J. R. Vilella, G. E. Guellich and E. C. Bain: *Trans. Am. Soc. Metals*, Vol. 24, 1936, page 225.

3. Figs 14 to 18 were made several years ago and have appeared previously in the literature.

4. For a more detailed discussion of "bainite" see METALS AND ALLOYS, Vol. 8, January, 1937, pages 22-24.

Replies to the Sauveur Questionnaire

IN the June issue of METALS AND ALLOYS, page 137, there was published a brief article by Dr. Albert Sauveur entitled—"Wanted: An International Committee on Nomenclature."

Dr. Sauveur sent copies of this article to some 53 well-known metallurgists and students of metallography, accompanied by a request for replies to the following three questions.

1. Do you favor recasting the definitions of pearlite, sorbite, and troostite along the lines suggested by some writers as outlined in this brief article?

2. Do you not think that, if a revision of the nomenclature is advisable, the matter should be referred to an International Committee?

3. Do you authorize the mention of your name in reporting the answers to this questionnaire?

The result of this questionnaire is as follows, as supplied by Doctor Sauveur with running comment:

Replies from American Metallurgists

THE questionnaire was sent to 32 Americans and replies have been received from 29. In the reverse order of the questions the replies were as follows:

Question No. 3

Only one expressed his unwillingness to have his name mentioned. He will be referred to hereafter as "Mr. X."

Question No. 2

Twenty-four have replied in the affirmative, the following without comment. H. M. Boylston, H. C. Boynton, John Howe Hall, V. O. Homerberg, Samuel L. Hoyt, F. F. Lucas, G. A. Reinhardt, F. T. Sisco, Bradley Stoughton, W. P. Sykes, Kent R. Van Horn, G. B. Waterhouse, Joseph Winlock, and Mr. X.

The following men have added some remarks to their replies to this question:

R. S. Archer: "Yes. Should have committee action. Such committee might be made up from nominees proposed by various technical societies, A.S.M., A.I.M.E., and A.S.T.M. for the United States, Iron and Steel Institute for Great Britain."

Edgar C. Bain: "It would be desirable possibly from time to time if a committee ascertained in what sense words are being employed and set down definitions of their meanings, as this is established, as in a dictionary. I think that changes in meaning of words are taking place constantly."

A. B. Kinzel: "I am so heartily in accord with your suggestion of an international committee that I should like to venture the following suggestion for more quickly getting such committee formed. If you would write to the executive committee of the Iron and Steel Division of the A.I.M.E. asking them to support such a committee, I am reasonably sure that they would take rapid action and that as a result we might even have the American and British representatives of such a committee meet in this country in the fall. This would certainly give the matter real impetus and lead to an early solution of the problem."

H. H. Lester: "Yes, after careful studies and suitable time for crystallization of thought on the part of the interested scientific public."

W. Mathesius: "Yes, for the reason that international agreement is essential in the interest of clarity and understanding."

J. H. Nead: "If a revision of the nomenclature is advisable, I agree that the matter should be referred to an international committee."

H. B. Pulsifer: "Recommendations of an international committee would have a strong influence and prompt effect in order to establish a new definition."

H. A. Schwartz: "That would be very desirable."

R. S. Williams: "Definite name changes should be made only after the most careful consideration by an international committee. Surely it should not be done in this country alone."

Four metallurgists do not recommend action by an international committee, at least at this time. They write:

H. W. Gillett: "No. I think it entirely unnecessary to be that formal about it, and I would prefer to have the topic seasoned by discussion, including getting foreign opinion. I do not think the time is ripe for formal international action . . ."

John Johnston: "In reply to the second question I should not be in favor of referring any such question at this time to an international committee, as I have no great confidence in the wisdom of any such committee. In any case I believe that it should not be referred to an international committee until there is substantial agreement in this country on the usage of these terms."

Oscar E. Harder: "It seems probable the metallurgists in this country could work out a satisfactory set of definitions without the rather long drawnout procedure of having an international committee. In fact, there are several committees which are now working on this problem and the work of various interested committees could probably be made the basis for at least a preliminary report. Current literature is rather rapidly shifting to some changes in nomenclature."

Clyde E. Williams: "I believe that the definition of pearlite, sorbite and troostite should not be recast at this time and that the time is not ripe for consideration by an international committee."

Question No. 1

The following have replied "yes" without comment: F. F. Lucas W. P. Sykes, and Mr. X; while Francis B. Foley, G. A. Reinhardt, and Joseph Winlock have replied "no" without further remarks.

No attempt will be made to classify the replies received from the other men, but they will be given here in their own words.

R. S. Archer: "No, but new terminology should be adopted to distinguish between sorbite and troostite formed (a) on cooling and (b) on tempering."

E. C. Bain: "I favor the suggestions of Vilella, Guellich, and Bain, *Trans.* A.S.M. 1936, v. 24, p. 225, who restrict pearlite to structures judged to be *lamellar,* not acicular, and formed directly from austenite. I do not favor the recasting as set up and attributed to 'some' writers in your article."

Henry C. Boynton: "Not immediately, that is not until the international committee has reported."

H. W. Gillett: "Bain's sorbite definition is satisfactory. Sorbite definitely should be restricted to the product born from martensite. I am willing to accept his definition of pearlite, but I would not abandon the term troostite. See editorial, METALS AND ALLOYS, June, 1938."

Marcus A. Grossmann: "While I am in somewhat of a quandary as to just how to reply to the three questions in your recent questionnaire, I should like to record my views in regard to the term 'pearlite.'

"I favor designating as pearlite all structures which, because of their direct formation from austenite at high temperature, are lamellar. It is true that the lamellar structure is sometimes so fine that the lamellae are scarcely distinguishable, and therefore constitute the structure which is now usually referred to as 'nodular troostite.' Under these circumstances however, the mode of formation is so clear, partly because of the nodular form and partly because in a freshly quenched piece it is associated with martensite, that there is little doubt that the structure was formed at a high temperature, directly from austenite.

"Under this designation, some of the structures now termed 'sorbite' would also be called pearlite, namely those which are lamellar because of forming directly from austenite at high temperature. Such designation would mean of course that the term 'pearlite' would be based solely on the lamellar structure, independent of the composition. This independence of composition is already justified in part by the fact that the eutectoid pearlite of alloy steels often contains far from the 0.85 per cent C of pure iron-carbon alloys. Thus the low alloy steels show eutectoid pearlite in the range 0.50 to 0.75 per cent C, and in 12 per cent chromium steels the eutectoid (with its pearlitic structure) is even as low as 0.35 per cent carbon."

John Howe Hall: "No, not if that is their view."

Oscar E. Harder: "I favor some work toward redefining some of the microstructures in steel as compared with the committee report of 1912. I am not in agreement with all of the ideas outlined in the article submitted."

V. O. Homerberg: "The use of pearlite for structures such as sorbite and troostite, which are obtained under non-equilibrium conditions, leads to confusion. I am in favor of restricting the term pearlite to the Fe-C eutectoid obtained under equilibrium conditions. In other words, retain the meaning of this term in accordance with the definition given to it by the 1912 committee.

"It has been pointed out by a number of investigators that sorbite and troostite when obtained by varying the cooling rate of austenite are lamellar in structure when examined at high magnifications. Since sorbite and troostite when obtained by tempering martensite do not possess such an appearance, I recommend that qualifying terms should be affixed to the names of these structures in order to distinguish those obtained by quenching austenite from those obtained by tempering martensite.

"If the word 'primary' is appended to the terms sorbite and troostite when obtained by varying the cooling rate of austenite and if the use of these terms without any qualifying word or the use of the term 'secondary' is confined to the structures obtained by tempering martensite, I feel that any possibility of confusion will be eliminated . . .

"It is unfortunate that sorbite and troostite have been used for structures obtained under two different conditions, i.e., quenching austenite and tempering martensite, but the use of pearlite to include sorbite and troostite obtained by quenching austenite will only further confuse the matter."

Samuel L. Hoyt: "Yes, particularly for the structures of quenched or rapidly cooled steel."

A. B. Kinzel: "As to Item No. 1 of the questionnaire, it is very difficult to give a clean-cut yes or no without knowing exactly what the new definitions would be, but I am certainly in favor of restricting the use of the term 'pearlite' to a lamellar structure and believe that the difference in type of lamellar structures found in certain 'troostite' and 'sorbite' is such that they should be given a separate designation which might be simply 'lamellar troostite' and 'lamellar sorbite.' I believe that we lose much by making the term 'pearlite' so broad as to fail to precisely define the microstructure with which we are dealing."

H. H. Lester: "I favor possible recasting of definitions after proper study by competent men."

W. Mathesius: "I would be interested in having the question reviewed impartially for the purpose of determining the merits, in the light of our present knowledge and with reference to our present technique, of definitions of pearlite, sorbite and troostite, beginning with the report of the committee organized in 1910 by the International Association for the Testing of Materials, and including the various proposals made since then by authoritative writers, for instance by Vilella, Guellich and Bain, *Trans.* A. S. M. 1936, V. 24, p. 225."

J. H. Nead: "I see no valid nor convincing reason for changing the definitions of pearlite, sorbite, and troostite. In my opinion the proposed broader definition of pearlite to include all aggregates of ferrite and cementite would be confusing rather than clarifying in effect."

H. B. Pulsifer: "Since 1912 so much has been learned about the decomposition of austenite that the conceptions of that date have been greatly modified. Our definitions certainly need revision."

H. A. Schwartz: "The traditional use of these terms has met my needs. Perhaps a fourth generic name covering all three should be introduced which might also be not limited as regards carbon content."

F. T. Sisco: "I prefer to retain the term pearlite for a constituent of eutectoid composition using prefixes lamellar or granular to describe structural appearance, and object to use of pearlite to describe an aggregate of ferrite and cementite of any carbon content. With such terminology sorbite could be discontinued. I am undecided concerning troostite."

Bradley Stoughton: "I think it would be most desirable for the reason stated in the reprinting of Professor Sauveur's article."

Kent R. Van Horn: "Yes, I favor recasting definitions of sorbite and troostite, but not necessarily in the manner suggested in the editorial."

G. B. Waterhouse: "Yes, at least considering them."

R. S. Williams: "May I say that I am completely in sympathy with you with regard to the names of the steel constituents. Having been brought up during the last century as a metallographist I have come to recognize the names pearlite, sorbite and troostite so intimately that I would be extremely sorry to have those names disappear from the literature."

Clyde E. Williams: "As one who has attempted to apply the fundamentals of metallurgy without having had an extensive training in them, I believe that the present definitions and general understanding of the meanings of the constituents in question serve the metallurgical fraternity satisfactorily although they may be entirely unsatisfactory to the scientists who are studying them from the fundamental point of view. Any abrupt change may make for confusion in the mind of the general reader and not be of any particular advantage to the fundamental worker. Usage will gradually change and go in the most practical and sensible direction."

Replies from Foreign Metallurgists

THE questionnaire was submitted to 21 foreign metallurgists. Replies have been received to date from 15. They all permit the use of their names in reporting the answers. They all favor referring the questions of nomenclature to an international committee.

Question No. 2

The following have answered "yes" to this Question: N. Belaiew, Harry Brearley, H. C. H. Carpenter, O. W. Ellis, P. Goerens, Kotaro Honda, Gordon Sproule, A. Westgren.

Some have commented as follows:

Carl Benedicks: "Yes, eventual revision should be referred to an international committee."

C. H. Desch: I think that your suggestion of an international committee is a good one.

W. H. Hatfield: "The only way of obtaining international agreement is by referring the matter to an international committee."

Albert Portevin: "The nomenclature having been established by an international committee, any revisions *must* be referred to such committee. It seems to me that the International Association for the Testing of Materials, which sponsored the first nomenclature committee, should again undertake this work."

Alfred Stansfield: "Yes, I think that so important a change in nomenclature should be considered by an international committee."

F. C. Thompson: "If it is decided to introduce a revision of the nomenclature, it is obviously desirable that this should be done on an international basis."

Question No. 1

To question 1 the foreign metallurgists consulted have replied as follows:

N. Belaiew: "May I refer to the concluding lines of my written discussion of the paper on Naming the Aggregate Constituents in Steel, by Vilella, Guellich and Bain, *Trans.*, Am. Soc. for Metals, June 1936:

"To sum up, we should welcome the materialization of the authors' suggestions for the better definition and classification of the constituents on cooling and on tempering, *but should like to see this end achieved with a minimum departure from the views of the fathers of the present day nomenclature, Osmond and Howe,* and also, from the present day practice, which in the main is following them. This could be arrived at, *by continuing the use of the names pearlite, sorbite and troostite*—in the 'cooling' (lamellar) series, and by the extension of the designation *OSMONDITE* to cover the temper structures."

Carl Benedicks: "No. To me the description, given by Osmond, of the series troostite, sorbite, pearlite, is a masterpiece of sharp observation and intuition. So far, I think there is no actual need of any change. We have the rational description involving that in *troostite* the transformation has already started, in *sorbite* it is not yet fully accomplished, in *pearlite* it is fully accomplished.

"*Troostite* is the state of *colloidal* distribution of the cementite; in *sorbite* some colloidal character still prevails.

"To abolish these terms would appear as a regress in old times of lacking knowledge; it would be as justified as would be the dismissing from chemistry the conception of colloidal state."

Harry Brearley: "No."

H. C. H. Carpenter: "Yes."

C. H. Desch: The question which you set in your letter to METALS AND ALLOYS is a difficult one to answer. I did not write at once because we are considering the problem here in connection with work on alloy steels. It is obvious that alloy steels, in which the transformations are so commonly retarded by other elements, present great difficulty in the way of naming the constituents. For the alloy steels committee of the Iron and Steel Institute we have determined very accurately a large number of cooling curves of different alloy steels under varying rates of cooling. At the same time a micrographic study has been carried on, and our problem is to correlate the two sets of results. I do not think that the 1912 definition of pearlite is satisfactory under present conditions. It will, in any case, need to be altered, as in the pure iron carbon alloys the eutectoid point is much nearer to 0.82 than to 0.90. Again, the improvement in microscopic technique has made it clear that much that has been described as sorbite is merely pearlite of very fine structure. When, however, the mixture of ferrite and cementite is not in eutectoid proportions the question of definition becomes much more difficult.

O. W. Ellis: "I do."

Federico Giolitti: "No."

P. Goerens: "No."

W. H. Hatfield: "Yes, I do favor recasting the definitions of pearlite, sorbite and troostite."

Kotaro Honda: "I do not agree to the definitions proposed by some writers, and those universally adopted are better."

Albert Portevin: "It seems to me neither necessary nor opportune to upset the definitions that have been accepted to date, as the advantages to be derived from certain changes would not compensate for the complications and obscurity which would result for those actually engaged in metallographic work in the industry.

"There is need, however, to clarify and to limit these definitions in view of the work done in the last 20 yrs. in studying the hardening of steel."

Edward Maurer: "No."

Alfred Stansfield: "I understand that the proposal is, essentially, to extend the use of the word 'pearlite' to include those structures in more rapidly cooled steel that are called 'sorbite' and 'troostite' which have been found to be lamellar when highly magnified.

"I recognize the objections: (1) that the appearance of sorbite and troostite under low magnifications is unlike that of pearlite, and (2) that the carbon content may differ from that of normal pearlite.

"On the whole I am inclined to favor the changes, regarding these differences as those of *degree* only, because: (1) the ultimate structures of the three appear alike when each is sufficiently magnified, (2) the carbon content of pearlite in non-eutectoid steel depends on the slowness of cooling and the extent to which the pre-eutectoid ferrite or cementite has separated. No pearlite in such steel will be of strictly eutectoid composition unless the steel has been cooled infinitely slowly."

Gordon Sproule: "Not unless the matter is considered more completely, as by a committee such as is suggested in Question No. 2. I believe, however, that there are grounds for the suggested change."

A. Westgren: "No."

General Remarks by Dr. Sauveur

THE opinions of those consulted are nearly unanimous that the proposed change in the nomenclature of some of the microscopical structures of steel should be referred to an international committee.

It seems evident that many failed to answer Question 1 with full understanding of its implication. They replied as if they had been asked if they considered recasting of the definitions of pearlite, sorbite, and troostite advisable without giving due consideration to the qualification "*along the lines suggested by some writers as outlined in the article submitted,*" which signifies, expressed in a few words: "Would you favor the recasting of the definition of pearlite so as to make it to include some structures which in the past have been described as sorbite and troostite?" It is not believed that many would have answered in the affirmative.

It has been stated that in my reference to the views held by those who favored a revision of the definition of pearlite I had not expressed their views correctly. Dr. Johnston, for instance, writes: "May I add that in your article enclosed with your letter in stating 'some writers have proposed to describe as pearlite all aggregates of ferrite . . .' you have not quoted Vilella, Guellich, and Bain quite correctly; it should, we think, be 'all *lamellar* aggregates.' "

In Dr. Bain's opinion the views held by himself and his associates should have been expressed in the following terms:

> "In recent years, however, some writers have described as either pearlite or fine nodular pearlite all apparently

(Continued on page 236)

STABILITY OF

Some Alloys for Springs

COMPARED

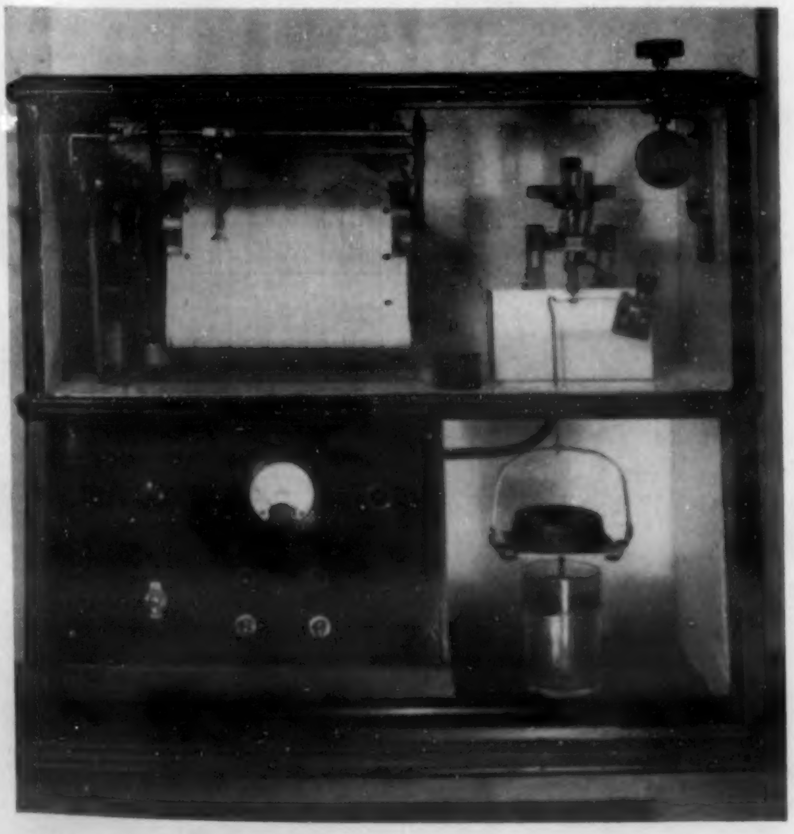
by L. L. Stott and R. W. Carson

Beryllium Corp. of Pennsylvania, Reading, Pa. and Instrument Specialties Co., Little Falls, N. J., Respectively.

The ability of a material to retain its "springiness" under the loads applied in service depends on its resistance to drift, or creep at low temperatures. The unusually accurate drift measurements reported in this article show that a salt bath heat-treatment at 650 deg. F. for 20 min. gives minimum drift in beryllium copper strip cold-rolled 4 B&S numbers hard. Spring temper phosphor bronze has 2.8 times as much drift as beryllium copper; nickel-silver has 1.4 times as much as beryllium copper when heat-treated as above. The information in the article was compiled from tests made in the laboratory of the Instrument Specialties Co., Little Falls, N. J.

—The Editors

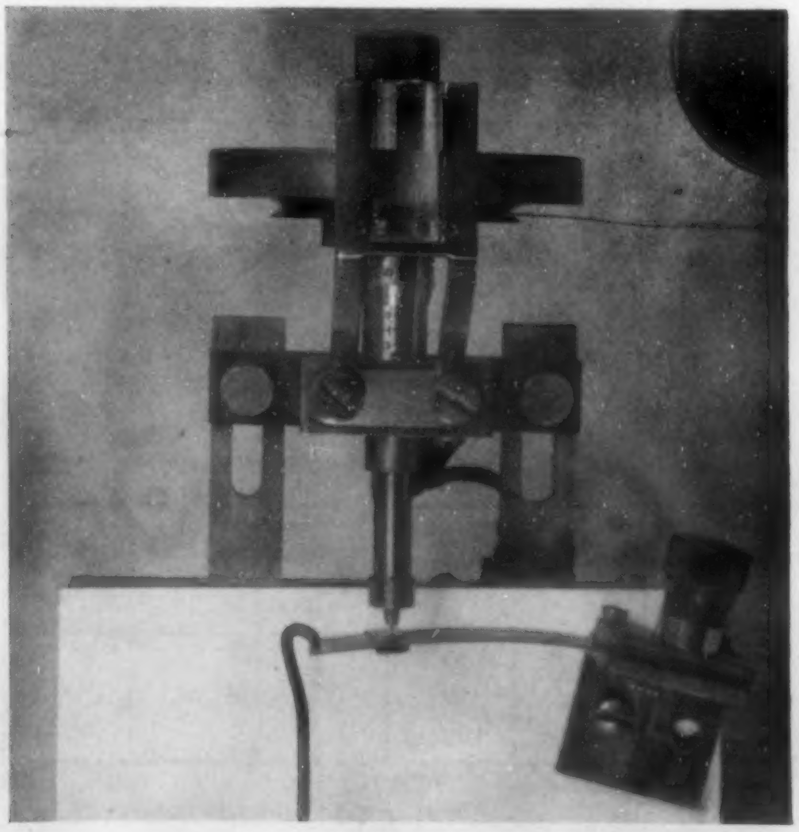
Fig. 1. Electronic Micrometer Used for Measuring Drift in Small Specimens Clamped beneath the Measuring Head and Loaded with a Weight.



ABILITY OF A SPRING MATERIAL to maintain a constant deflection under a steady load depends on the stability of the material. Lack of stability results in drift or hysteresis which is a slow increase in deflection that continues indefinitely at a constantly decreasing rate.

Drift or hysteresis is known to increase with an increase in working stress. At low stresses nearly all of this drift is recovered when the load is removed. At high stresses some of the drift is permanent, this permanent phase merging with plastic flow or permanent set at stresses above the elastic limit.

Fig. 2. Measuring Head with a Needle Point Automatically Kept just Touching the Specimen.



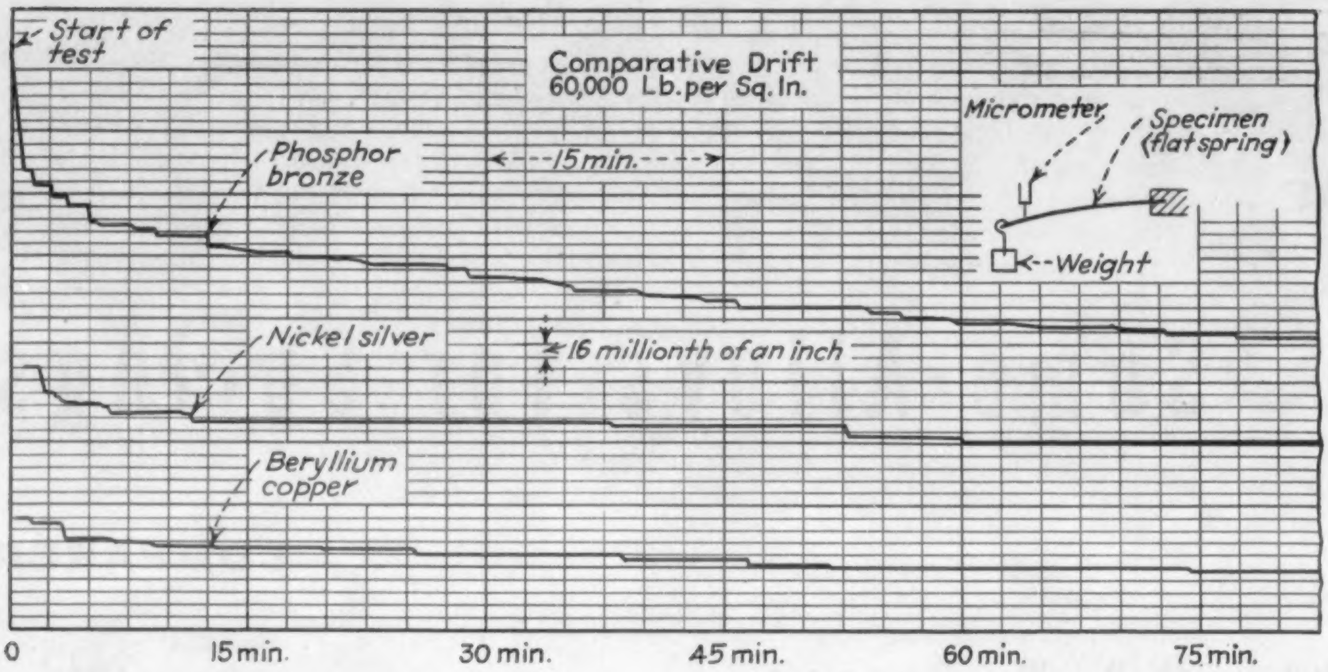


Fig. 3. Typical Chart Record for One of the Comparative Tests.

Drift is also known to be increased by internal stresses or conditions associated with the cold working that increases the strength of non-ferrous metals. Heat treatment that tends to relieve internal stresses reduces drift. The temperature of the material when it is under load also affects drift, elevated temperatures causing more rapid changes.

Measuring Drift

Tests previously made indicated that beryllium copper was exceptionally free from drift or creep after heat treatment at a relatively high temperature. To compare the performance of 2.25 per cent beryllium copper, phosphor bronze (8 per cent Sn), and nickel- silver, (18 per cent Ni, 27 per cent Zn), stamped strips of each of these materials were supplied by a prominent laboratory for bend tests. These strips were approximately 0.020 in. thick, ½ in. wide and 6 in. long. The phosphor bronze and nickel-silver were furnished cold-rolled 6 B & S numbers hard and the beryllium copper 4 numbers hard.

Strips about 4 in. long were subjected to steady bending stresses by loading them as cantilever beams. Drift or increase in deflection under a steady gravity load was measured and recorded automatically on the electronic micrometer shown in Fig. 1. This device consists of a hand type micrometer with a needle point making contact with a polished steel clip attached to the specimen, as shown in Fig. 2. With electronic means of determining instant of contact, and a relay controlling a motor for setting the micrometer exactly at the point of contact, drift in the specimen is recorded on the moving paper chart, entirely eliminating any personal factor in making measurements. The instrument is sensitive to a drift effect as small as one millionth of an inch. (For further details regarding this instrument, see "Measuring Elastic Drift", *Proceedings,* American Society for Testing Materials, Vol. 37, Part II, 1937, pages 661-674.)

Chart records were obtained on each of the materials at calculated maximum fiber stresses of 30,000, 60,000 and 90,000 lb. per sq. in. Most tests were run for an hour or longer. Test temperature was held at 20 deg. C. (68 deg. F.) For beryllium copper specimens, strips were heat-treated for various lengths of time at 575, 615 and 650 deg. F. Additional tests were made on strips 0.013 in. thick and 5/16 in. wide, that had been previously prepared and tested for hardness. The strips used were those

Fig. 4. Drift in Beryllium Copper, Heat Treated at 650 deg. F. for 20 min. Bending stress, 60,000 lbs. per sq. in.

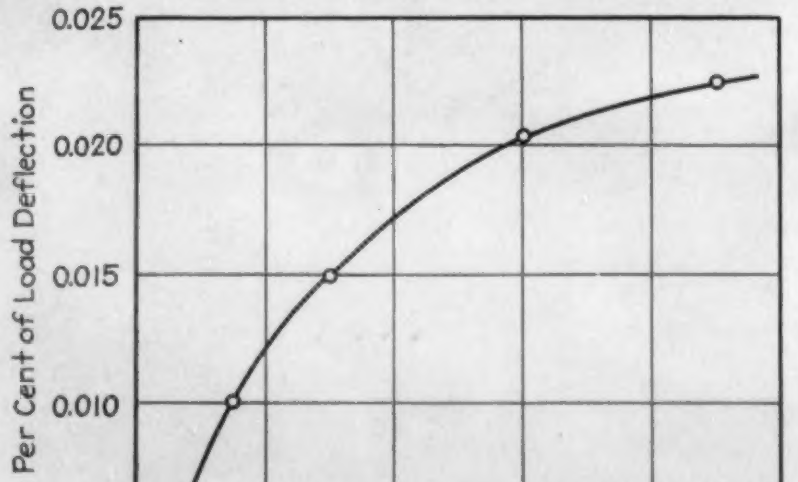
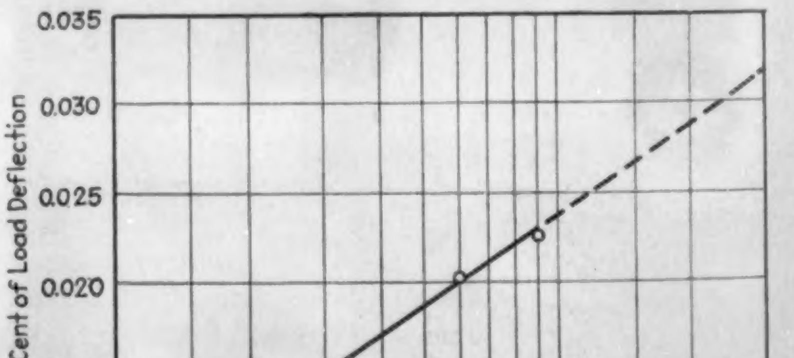


Fig. 5. Drift in Beryllium Copper. Time plotted to logarithmic scale for drift under bending stress of 60,000 lbs. per sq. in. Heat treated at 650 deg. F. for 20 min.



that hardness tests showed to be heat-treated to maximum hardness. All heat-treating was in a salt bath.

From these recording micrometer measurements, the heat treatment was found that gave minimum drift in beryllium copper, and this heat treatment used for strips used in comparative tests. In all tests, a complete set of specimens of each material were subjected to the same stress under identical load conditions.

Interpretation of the Records

A typical chart record for one of these comparative tests is shown in Fig. 3. (Stepped records are the result of a controlled amount of overshooting in the recording mechanism which minimized the effect of stray vibrations.) To obtain a better conception of the character of the drift, the chart record for beryllium copper is transferred with a condensed time scale on Fig. 4. This curve shows the characteristic of drift as it is found in all materials; that is, rate of drift decreases with increasing time under load.

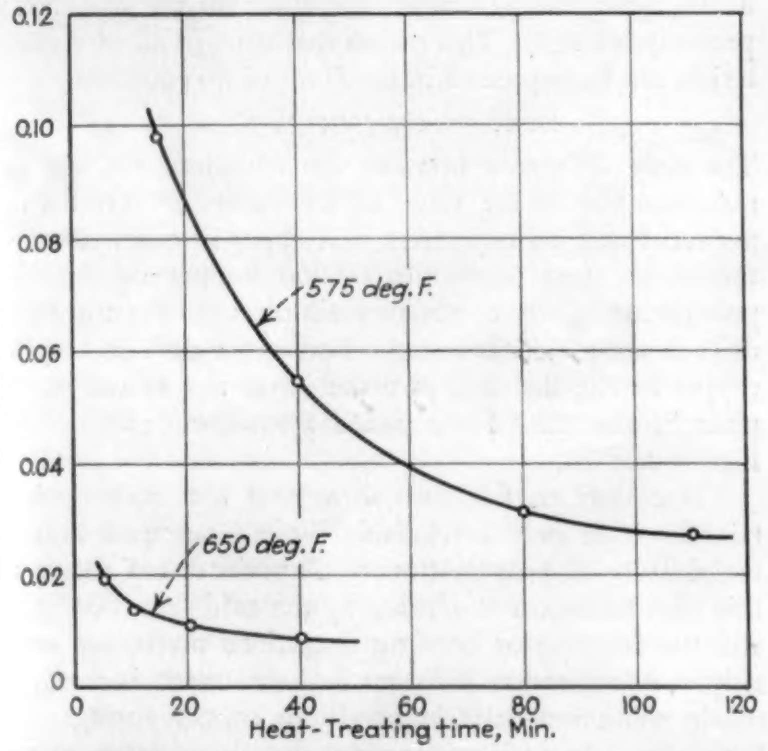


Fig. 6. Drift in Beryllium Copper, Following Heat Treatment at 575 and 650 deg. F. Drift in per cent of load deflection for first 30 min. under load. Bending stress 60,000 lbs. per sq. in.

In this chart, drift is shown in per cent of load deflection, rather than as the actual measured displacement. Since materials with different elastic constants deflect different amounts under the same stress, drift in per cent of deflection is a more useful basis of comparison. Otherwise, it would be necessary to qualify drift measurements with information on the specimen dimensions, load weight and lever arm. Therefore, all drift measurements in this investigation are expressed in per cent of load deflection.

The curve shown in Fig. 4 appears to flatten out, indicating that drift would stop at some extended time. However, by plotting the same data to a logarithmic time axis, as shown in Fig. 5, the points fall on a straight line. Experience has shown that if drift is measured with sufficient accuracy during the first hour or two, such a curve can be projected with reasonable certainty by extending this straight line, as has been done in Fig. 5. The drift never ceases, but of course soon reaches such a slow rate that further effects can be neglected. The slope of the line and

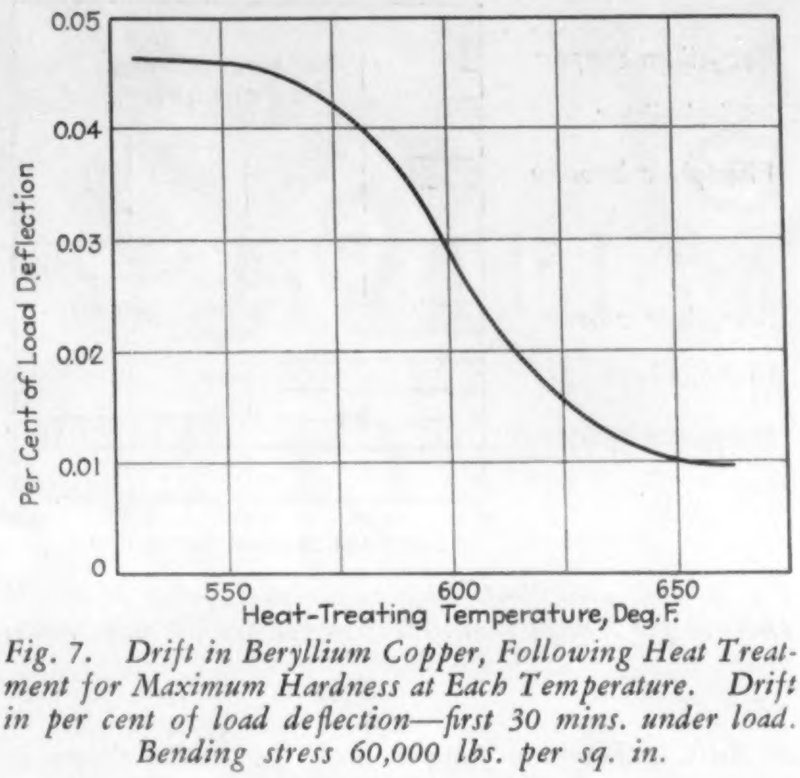


Fig. 7. Drift in Beryllium Copper, Following Heat Treatment for Maximum Hardness at Each Temperature. Drift in per cent of load deflection—first 30 mins. under load. Bending stress 60,000 lbs. per sq. in.

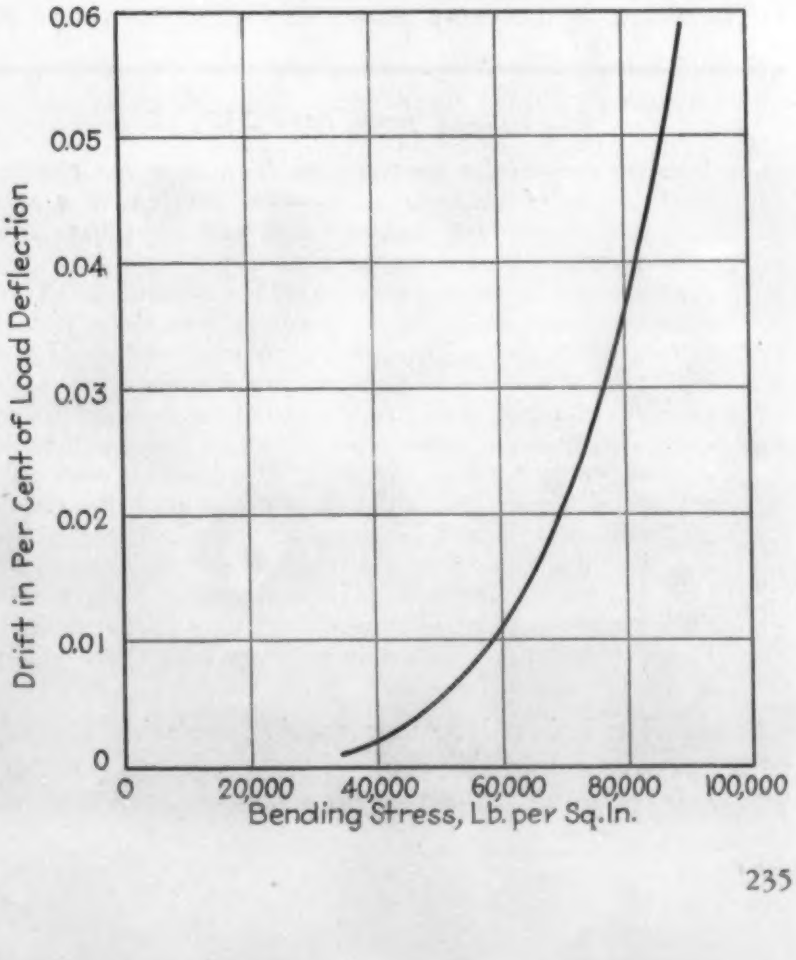
the amount of drift at any given time thus determines the stability characteristic of any material. If tests are made with sufficient accuracy, a test need run no longer than 30 min. to measure this property.

Because of the relatively rapid rate of drift during the first few minutes, readings taken during this time are subject to comparatively large errors. Therefore, in each of the measurements made on these materials, the drift was measured for the period from 2½ to 32½ min. after applying the load.

Effect of Heat Treatment on Drift

In preliminary tests it was found that a bending stress of 60,000 lb. per sq. in. gave a sufficient amount of drift to result in accurate determinations within 30 min. This stress was used to find the effect of various heat treatments

Fig. 8. Drift in Beryllium Copper. Effect of stress on drift during first 30 mins. under load. Heat treated at 650 deg. F. for 20 mins.



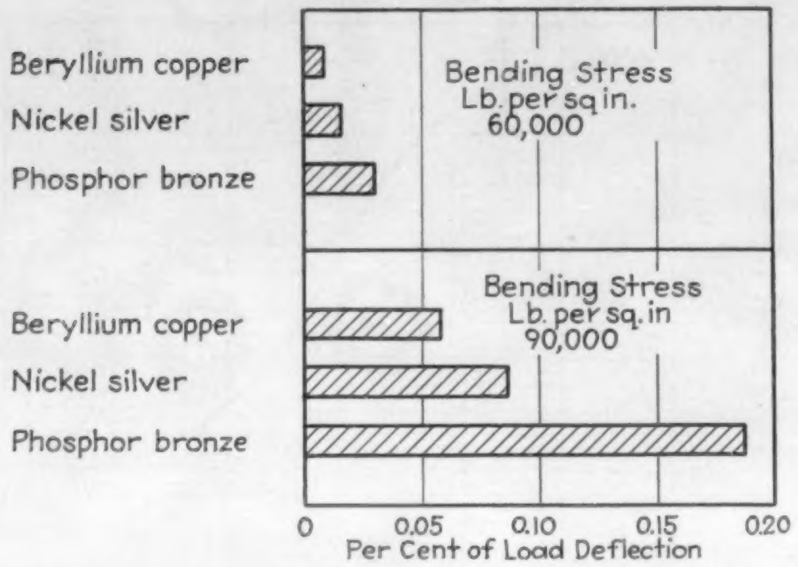


Fig. 9. Relative Drift in Non-Ferrous Spring Materials. Drift in per cent of load deflection for first 30 mins. under load.

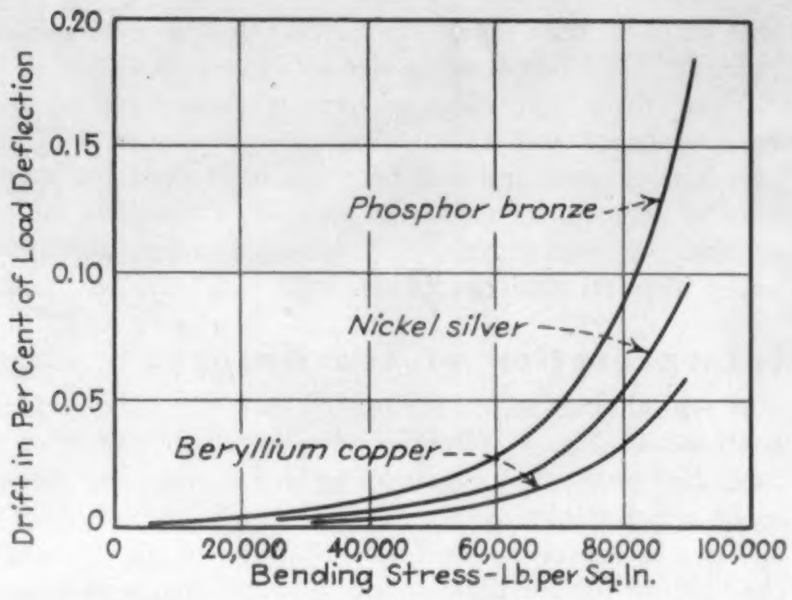


Fig. 10. Effect of Stress on Drift.

on drift in beryllium copper, with the results shown in Fig. 6. At 575 deg. F., minimum drift requires heat treatment for at least 2 hrs. At 650 deg. F. at the end of 5 min., drift is already much lower than the minimum obtained at 575 deg. F. Although minimum drift following 650 deg. F. requires 30 min. at temperature, softening during this time would reduce the strength. Therefore, a maximum time of 20 min. at 650 deg. F. was used for all subsequent tests.

Fig. 7 shows a little more clearly the effect of heat-treatment on drift. It is evident that a relatively high temperature is needed for maximum stability.

Effect of Stress

Small increases in stress cause large increases in drift, as shown in Fig. 8. Using a test time of 30 min., accurate measurements could be made only for stresses of 30,000 lb. per sq. in. and higher. The drift at lower stresses could be measured readily by extending the test time to 2 or 3 hrs. However, Fig. 8 shows that 40,000 to 50,000 lb. per sq. in. is the maximum working stress for beryllium copper springs that require stability.

The shape of the curve shown in Fig. 8 was found to fit all three materials when the scale for the ordinate was properly selected. This means that drift in all of these materials can be expressed in the form of an equation:

$$\text{Drift} = \text{constant} \times \text{stress}^{5.3}$$

The only difference between the equations for the three materials was in the value of the constant. Thus a comparison based on one stress will apply to other stresses in the range from 30,000 to 90,000 lb. per sq. in. It is possible therefore, to obtain a simple ratio for the relative drift in the materials tested. Rating the drift in beryllium copper as 1.0, the drift in nickel-silver is 1.4, and in phosphor bronze 2.8. These ratios are shown graphically in Figs. 9 and 10.

These tests on flat strip show that best stability is obtained within only a relatively limited range of time and temperature of heat treatment. Experience has shown that this heat treatment is affected by the cold reduction in area and the forming or bending operations performed on the strip. A somewhat different heat-treatment is needed to obtain minimum drift in beryllium copper springs coiled from wire. In such springs it is usually necessary to make a drift determination on finished springs in order to arrive at the best heat-treating time and temperature.

(Continued from page 232)

lamellar non-acicular structures resulting from the continuous cooling of austenite to room temperature at a subcritical (non-martensite-forming) rate, quite regardless of the carbon content of these aggregates. In other words, they now describe as pearlite, or perhaps fine-pearlite one of the structural types which in the past has been designated as troostite or sorbite. To illustrate: A small section (e.g. a 1/4 in. round) of a 0.40 per cent carbon steel cooled in air from its austenitic range, so generally considered as having a sorbitic structure, (apart from a trace of ferrite network), is described by them as consisting of pearlite, or more specifically of fine pearlite, although *that* pearlite being associated with only about 3 per cent free (pro-eutectoid) ferrite would contain little more than half the carbon of the eutectoid composition and appear rather irregularly lamellar in those areas which under the microscope were clearly resolved. Its ferrite lamellae would have to be some 14 times thicker than its cementite lamellae."

Finally, Dr. Robert H. Aborn would have said:

"In recent years, Vilella, Guellich and Bain (*Trans.* ASM 1936, V. 24, p. 225) have proposed to describe as pearlite all *lamellar* aggregates of ferrite and cementite, resulting from the cooling of austenite to room temperature, quite regardless of the carbon content and even though some of the lamellae, owing to their orientation, are not resolved."

It did not occur to me that it was necessary to explain that the term pearlite was to be applied to sorbitic and troostitic structures only when they were lamellar, because it was my understanding, and it still is, that all such structures obtained from the transformation of autenite were claimed to be lamellar, at least when examined under high magnification, and that all of them, therefore, were to be described as pearlite. Neither did it occur to me that I should have made it clear that acicular structures were not to be considered as pearlite, martensite being clearly out of the picture.

It is urged now that those who have kindly replied to the questionnaire again consider Question No. 1 in the light of these contentions and that I be notified if they desire to change their answer to this question.

[*See letter to the Editor,* page 242]

Vanadium in Steel and Iron

—A REVIEW

Part II

Concluded from August Issue

by W. J. Priestley

Vice President,
Electro Metallurgical Co.,
New York.

Manganese-Chromium-Vanadium Steels

The manganese-chromium-vanadium steels were developed originally for use as-normalized to replace certain quenched and tempered carbon and low-alloy steels whose heat-treating cycle included a drastic quench, which formerly resulted in high scrap loss. These steels were initially used in automotive crankshafts. In this service, their excellent mechanical properties, together with their resistance to warpage or distortion in machining or in service made them especially adaptable. Other applications in which these steels have since come into prominence are forgings of irregular contours and sections such as camshafts, wheel hubs, eccentrics and other highly stressed parts.

The usual composition of manganese-chromium-vanadium steel is given in the following table:[9]

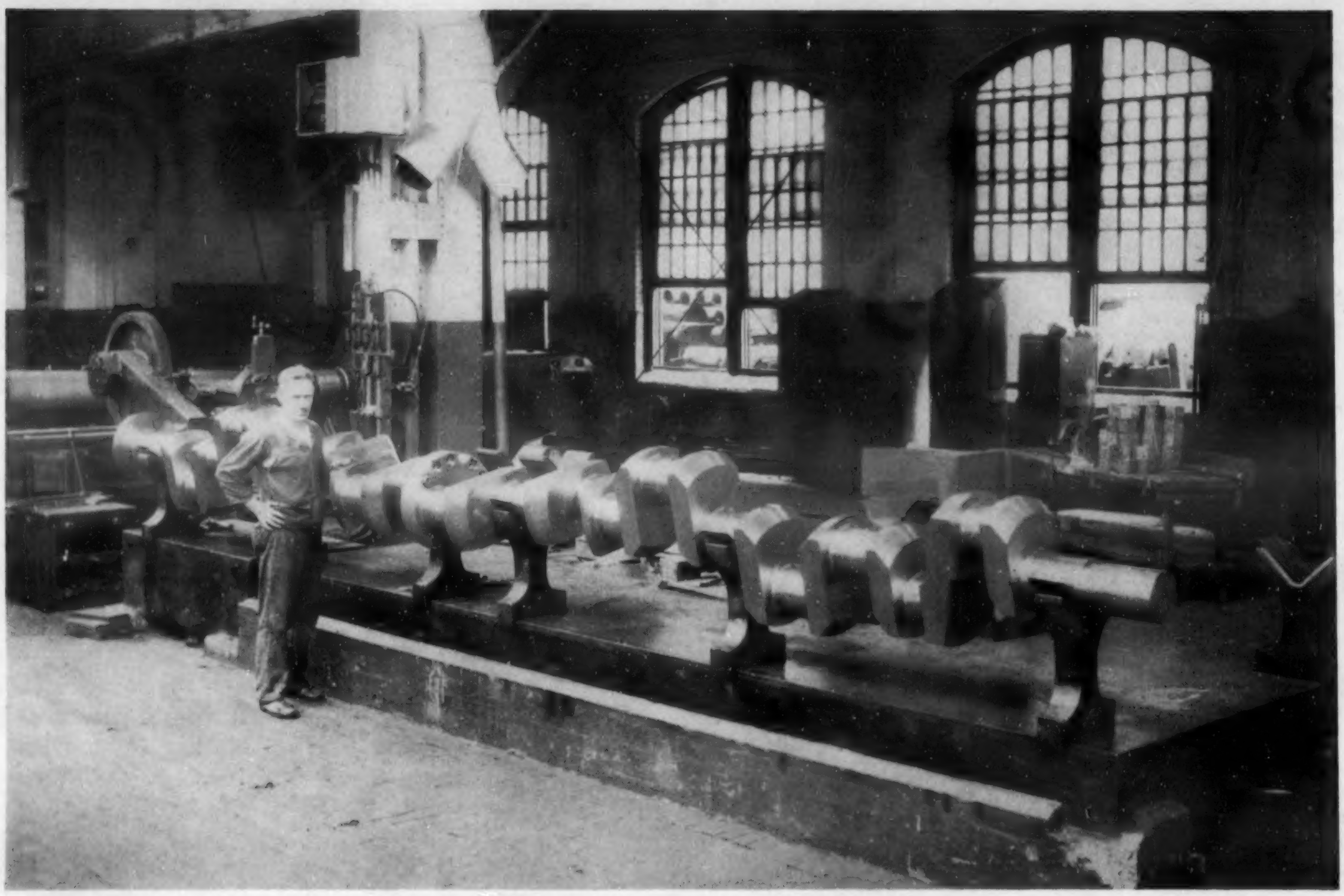
Carbon, per cent	0.15 to 0.50
Manganese, per cent	1.00 to 1.60
Chromium, per cent	0.30 to 0.65
Silicon, per cent	0.15 to 0.30
Phosphorus, per cent	0.04 max.
Sulphur, per cent	0.05 max.
Vanadium, per cent	0.12 max.

Special Vanadium Steels

Special vanadium constructional steels include principally those alloys which contain nickel and molybdenum, and usually chromium. A chromium-nickel-vanadium steel containing approximately 0.50 per cent each of chromium and nickel and the usual amount of vanadium has been found very suitable for automotive ring gears and other parts where freedom from warpage is an essential requirement and a fine machined finish is necessary.[9] It is usually used in the carburized and hardened condition.

When molybdenum is employed together with vanadium in steel, the manganese content seems to be a determining

Helical Springs of Chromium-Vanadium Steel and Elliptical Springs of Silicon-Vanadium Steel in the Trucks of Cars on the New "Twentieth Century" Assure Greater Riding Comfort. (Courtesy: The New York Central System.)



Large High-Strength Forgings are Made of Steel Containing Vanadium. Observe the size of this crankshaft. (Courtesy: The Midvale Co.)

factor. A manganese-molybdenum-vanadium steel is used for tubes, plates, and other parts subject to service at elevated temperatures. At 1,000 deg. F., under stress in excess of 18,000 to 20,000 lb. per sq. in., the rate of creep of this steel is actually less than that of the well-known 18-8 chromium-nickel stainless steel.

The mining industry uses a number of special vanadium steels. Chisels contain 1.35 to 1.45 per cent chromium, 2.3 to 3.0 per cent tungsten, and 0.18 per cent vanadium. Hollow drills give very good service when they contain 0.20 to 0.30 per cent molybdenum and 0.15 to 0.25 per cent vanadium. Shovels, and dipper and drag buckets, possess a high degree of abrasion resistance when made of steel containing from 0.40 to 0.60 per cent chromium, 1.10 to 1.40 per cent manganese, 0.70 to 0.80 per cent silicon and 0.10 per cent vanadium. Knocker bars last a long time when made of a composition containing 0.12 to 0.18 per cent silicon and 0.22 to 0.28 per cent vanadium.

An interesting special exhaust valve steel for use in gasoline motors has the following composition:[10]

Carbon, per cent	1.00
Silicon, per cent	2.00
Manganese, per cent	1.40
Nickel, per cent	1.05
Chromium, per cent	14.00
Tungsten, per cent	4.00
Vanadium, per cent	0.20
Molybdenum, per cent	0.50

This steel is unusual in that it possesses a high tensile strength at elevated temperatures. Usually cooled by sodium metal which fills the hollowed-out center of the valve, the steel operates at about 600 deg. C. under ordinary conditions. The following table, showing the tensile strength of such steel at various temperatures above 600 deg. C., may be of interest to automotive engineers:

Temperature, deg. C.	Tensile Strength, lb. per sq. in.	Elongation, per cent	Reduction of Area, per cent
600	81,000	10	31
700	39,000	22	54
800	24,000	47	72
850	19,400	30	66

Valves of this material faced with non-ferrous hard-facing alloy have proved to be exceptionally worthy in airplane racing motors.

Spring Steels

In general, there are three types of spring steels containing vanadium,[9] the well-known chromium-vanadium, the silicon-vanadium, and the more recently developed carbon-vanadium types. The most common steels for spring service are the chromium-vanadium steels of the S.A.E. 6100 series. S.A.E. 6150 chromium-vanadium spring steels, in the heat-treated condition, usually have a Brinell hardness of from 360 to 460; at the same time, the tensile strength ranges from 175,000 to 230,000 lbs. per sq. in.

The best temperatures for stamping and forming spring leaves depend upon the percentage of chromium and vanadium. S.A.E. 6150 steels with a chromium content of 0.80 to 1.10 per cent and a vanadium content of approximately 0.18 per cent are usually rolled between 1,000 and 1,250 deg. C. Springs are usually formed at a temperature of from 900 to 1,050 deg. C. Steels of higher alloy content are worked at higher limits of temperature. In the subsequent heat treatment, the temperature is slowly raised to 800 deg. C., and the steel is quenched in oil to room temperature. Reheating for drawing the hardness should be for not less than 1/2 hr. in an oil bath not exceeding 300 deg. C. The steel should then be cooled in oil.

S.A.E. 6150 steels have been used in considerable

amounts for both flat springs and coil springs. They are usually made from either flat bars, or round, flat, or square wire. Generally, coil springs made from this steel are from bars not exceeding 5/8 in. in diameter or thickness. Flat springs in all but the smallest thicknesses are hot rolled and are converted into assembled elliptical or semi-elliptical springs of many leaves, such as for automotive chassis.

Silicon-vanadium spring steel is usually made in the following composition:

Carbon, per cent	0.60 to 1.00
Silicon, per cent	0.50 to 0.75
Sulphur and phosphorus, per cent	0.045 max.
Manganese, per cent	0.45 to 0.65
Vanadium, per cent	0.15 to 0.20

As will be observed, the carbon content is given in a rather broad range. Actually, the carbon content is adjusted to the size and nature of the particular spring for which the steel is to be used. The lower carbon steels have been used for springs made of annealed cold-drawn wire, while higher carbon steels have been used for helical springs made from bars of large diameter, usually 1/2 in. or larger. As this steel possesses free-scaling qualities, minor surface imperfections are removed during hot working at the mill, making possible finished springs with an especially good surface.

For large helical springs such as those used in trucks of railway cars and locomotives, the heat treatment followed consists of a quench from between 860 and 900 deg. C. in oil, followed by tempering between the limits of 450 and 570 deg. C. to a Brinell hardness of from 380 to 444. The mechanical properties resulting from this heat treatment of the steels containing 0.88 to 0.98 per cent carbon in the bar sizes generally employed, are within the following range:

Tensile strength, lb. per sq. in.	195,000 to 220,000
Yield point, lb. per sq. in.	175,000 to 200,000
Elongation in 2 in., per cent	8 to 10
Reduction of area, per cent	20 to 30
Brinell hardness	380 to 444

Two types of so-called carbon-vanadium spring steels have recently been developed. The plain carbon-vanadium steel is of the following composition:

Carbon, per cent	0.65 to 0.75
Silicon, per cent	0.30 to 0.40
Sulphur and phosphorus, per cent	0.040 max.
Manganese, per cent	0.80 to 1.05
Vanadium, per cent	0.05 to 0.10

In addition to this steel, a similar composition containing chromium has been used with good results. The modification contains between 0.30 and 0.45 per cent chromium, together with a slightly lower manganese content, namely, 0.65 to 0.85 per cent.

In addition to these, the three most common vanadium-containing spring steels, several steels have been made which combine high creep resistance with excellent endurance qualities. These steels have been recommended for use at temperatures higher than those for which ordinary chromium-vanadium spring steels are suited. They con-

Vital Parts, Such as the Drum Shaft, Swing Shaft, and Jack-Shaft of this Large Shovel are Made of S.A.E. 6140 Chromium-Vanadium Steel. (Courtesy: Harnischfeger Corp.)

The Heart of this Trenching Machine is a Sprocket of S.A.E. 6150 Steel, which Withstands Every Shock of its Strenuous Service. (Courtesy: Cleveland Trencher Co.)

tain larger amounts of the alloying constituents ordinarily used, together with tungsten or molybdenum. Steels containing 1 to 2 per cent chromium, together with 0.20 to 0.40 per cent vanadium and about 2 per cent tungsten have been found useful. Others contain no chromium but derive their higher creep resistance from approximately 2 per cent silicon, 1 per cent manganese, and either 0.50 or 1.30 per cent molybdenum. In either case, the vanadium content is between 0.30 and 0.40 per cent.

Tool Steels

Vanadium is used in tool steel wherever extreme toughness is required. Ability to withstand extremely severe pounding or battering, combined with exceptionally good resistance to cracking and warping, is very easily obtainable by the use of vanadium in steel for tools.

The plain carbon-vanadium tool steels most frequently used are employed in punch and die adaptors; arbors; heading backing plates; heading cut-off blades; bushings; shear blades; blanking, clipping, drawing, embossing, notching, perforating, shaving, swaging and knife-edge dies; pads; pilots; punches for blanking, broaching and clippings; stops; and strippers. A high-carbon, high-chromium tool steel finds use in shear blades, knife edges, blanking punches, and perforating and flattening dies.[11]

Still another tool steel containing vanadium is a low-alloy oil-hardening steel used for cutting, forming and drawing dies and for cold stamping and coining operations that require a greater depth of hardness and better resistance to cracking and warping than ordinary high-carbon steel. An air-hardening, high-carbon, high-chromium steel containing 1 per cent vanadium and 1 per cent molybdenum is used for cutting, forming, and drawing dies to be used at extremely high production speeds or where a minimum of warpage and danger of cracking during hardening are required. For drawing and forming dies this material is usually furnished in the cast form.

For cutting butt- and lap-welded pipe to length and for cutting off ragged ends, rotary pipe cutters are usually of plain carbon or carbon-vanadium steel. Carbon-vanadium steel, or occasionally chromium-vanadium steel, is used in a number of minor applications around tube mills where good resistance to shock is required. Some of these applications include shear blades, grips for threading machines, welding rolls, chisels, and jaws on cold drawing benches.

The use of vanadium in high-speed tool steel is now so well known that it is hardly necessary to mention. However, it may be of interest to state here that tool steels containing molybdenum and chromium, with tungsten and vanadium have been receiving much attention in the last few years. Steels with 7 to 9 per cent molybdenum, 3 to 5 per cent chromium, 1 to 2 per cent tungsten and 0.8 to 1.7 per cent vanadium are now quite popular. The cobalt high-speed tool steels which have come into wider application recently also require vanadium for finer grain structure and greater toughness.

Vanadium in Cast Iron

Vanadium in amounts from 0.10 to 0.15 per cent increases the strength of cast iron from 10 to 25 per cent and it adds a considerable amount of toughness as a direct result of the uniform grain size produced. Cast iron containing vanadium is especially valuable for applications such as steam locomotive cylinders, valve and piston bushings, piston rings, and similar parts. In steam engines equipped with vanadium cast iron cylinders, it has been found that these cylinders have greatly outlasted ordinary cylinders, and the amount of scrap in manufacture has also been

greatly decreased. These advantages have also been obtained in large diesel motors containing vanadium cast iron. Typical vanadium cast irons contain 1.3 to 1.8 per cent silicon, about 0.50 per cent manganese and 0.10 to 0.15 per cent vanadium.

Cast irons in which vanadium is the sole alloying element are used primarily in moderately high-temperature applications and in heavy sections requiring uniform hardness without brittleness. Included among these are locomotive cylinder blocks, grate bars, forming dies, bottle molds, and brass mill rolls. In some of these applications, plain vanadium cast irons have been used for many years.[9]

Established applications of cast iron containing vanadium are more often filled with an iron containing additional alloying elements. In most cases, these irons include a graphitizing element, although, in some instances only carbide-forming elements have been used, the necessary balance being obtained by carbon and silicon adjustment.

Chromium-vanadium cast iron rolls, containing up to 2 per cent of chromium, have been in use for many years in steel mills. The high chromium content has been found very advantageous for large sections. More recently, however, an application of this iron in very light sections has developed in the form of automotive engine clutch plates. The total alloy content is low, but in addition to the elements used, a small amount of titanium is added just prior to the introduction of the chromium and vanadium.

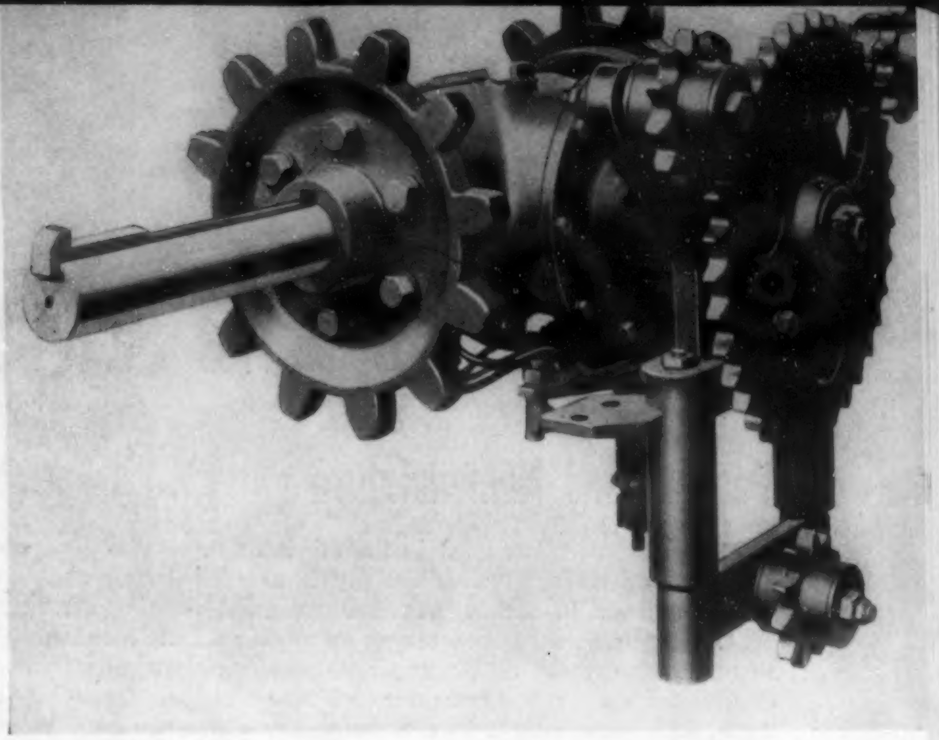
Nickel-vanadium cast iron is often used in heavy dies for forming and drawing automobile body parts. This iron has very good wear-resistance and has been standard in a number of foundries for several years.

Nickel-chromium-vanadium cast irons are used for dies, for chilled rolls, cold-rolling strip and similar applications. The addition of about 0.75 per cent chromium to the nickel-vanadium cast iron has increased the wear resistance of the resultant metal as well as increasing its hardness when the same ratio of combined to graphitic carbon is retained.[9]

A nickel-chromium-vanadium cast iron containing about 1 per cent silicon, 1 per cent manganese, 1.8 per cent chromium, 4 per cent nickel and 0.35 per cent vanadium has found wide use for rolls in the steel mill. This iron has a great depth of hardness and a tough and wear-resistant surface even though chilled in the mold.[12] The vanadium stabilizes the cementite, yielding smaller and more uniformly distributed graphite particles. It further promotes a sorbitic structure, decreases the grain size of the matrix and hence gives a tougher cast iron than could otherwise be obtained. Smaller, less pronounced and less perfectly aligned dendrites in the chilled surface insure a maximum of wear-resistance.

Nickel-molybdenum-vanadium cast irons are noted for their high strength. Their vanadium content is responsible for the major part of their desirable qualities. It is possible, with these alloying elements, to obtain a tensile strength in as-cast iron of over 60,000 lb. per sq. in. Iron of this analysis is now in experimental use in the form of brake drums, where its microstructure, containing a sort of decomposed martensite, is regarded as highly desirable.[9]

Titanium-vanadium cast iron in sections over 1/4-in. in thickness shows exceptional uniformity of structure and mechanical properties throughout large ranges of thickness. This, combined with high strength at both room and elevated temperatures, has resulted in its recommendation for use in diesel engine heads. Vanadium, in combination with titanium, prevents high-carbon, high-silicon irons from chilling readily even in thin sections. As a result, this iron has also been used successfully for piston rings.



Close-Up of the Driving Mechanism of a Cleveland Trencher, Showing the Vanadium Steel Digging Wheel Drive Split Socket. (Courtesy: Cleveland Trencher Co.)

A copper-vanadium cast iron has been suggested for use in brake drums and is in experimental use in molds for receiving molten metal. It has excellent properties regarding strength, growth, chill and microstructure. It contains approximately 2 per cent copper, and can be obtained with strengths in excess of 75,000 lb. per sq. in. It has a very satisfactory impact value, and is regarded as satisfactory for use in many cases where cast steels are now being used.

As a matter of interest, an exceptionally fine nitriding cast iron which has been developed for automobile cylinder liners is a complex alloy containing 2.90 per cent total carbon, of which 2.30 per cent is graphitic; phosphorus, 0.06 per cent; sulphur, 0.03 per cent; manganese, 0.75 per cent; aluminum, 1.0 per cent; vanadium, 0.18 per cent.

From the variety of applications of vanadium steels and irons, it is readily apparent that vanadium is an all-important element in producing better iron and steel. The rigid specifications for ordnance steel have, ever since the War, called for vanadium as an essential element. Vanadium produces higher strength steel and iron with much less exacting heat treatment, and with a lower cost for both heat treating and machining. With these advantages, vanadium will always be one of the most important alloying constituents for addition to steel in order to meet the requirements of highly stressed parts.

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Letters to the Editor

Pearlite and Nomenclature

To the Editor: Confusion in the minds of those who read what we write or listen to what we say is avoided if our choice of words is made in such a way that we make definite statements. Prof. Sauveur does right in asking us to give a little more thought to the use we make of words whose meanings have already been clearly defined by a Committee on Nomenclature, made up of those who come rather close to being the pioneers in the microscopical examination of metals, particularly of steel. To give a word a number of different meanings ruins the usefulness of the word. Here we had "pearlite" clearly defined by the committee in the words given in Prof. Sauveur's note. It is "the iron-carbide eutectoid—when pure, contains about 0.90 per cent of carbon, 99.10 per cent of iron." That was as definite as it could be made at the time. As you remark in your editorial precise methods of study have cut the carbon content of the eutectoid in 1938 to about 0.80 per cent, nevertheless, the definition of pearlite is still clear. Pearlite is of "eutectoid" composition. Structurally, pearlite consists "of alternate masses of ferrite and cementite." Pearlite, it seems to me, is clearly defined as of eutectoid composition and consisting of alternate masses of ferrite and cementite, and it would be a shame to vitiate the clearness of that definition.

Being the eutectoid, pearlite can only be produced by cooling austenite through its critical temperature at a rate which permits the eutectoid to appear in the form of alternate masses of ferrite and cementite. If the cooling rate be too rapid, pearlite does not form; if too slow, the cementite spheroidizes, so that the alternate arrangement is destroyed.

I have always used the name pearlite for those structures which show the alternate layers of ferrite and cementite at a magnification of 500 diameters. One has no means of analyzing to be certain that the exact eutectoid composition is present. Nevertheless, it has seemed to me that, generally speaking, one may assume that, if lamellae be clearly present at 500 diameters, the composition is approximately that of the eutectoid. Bain's work shows quite definitely that transformation must occur in carbon steel in a definite temperature range to produce pearlite.

The structures which have been called "fine pearlite" by some writers are shown to be lamellar at very high magnifications—actually at magnifications beyond the range available to most metallographists. Whether these structures are actually lamellar or only appear to be lamellar has been a question in my mind. I recall very well my experience some years ago in looking for spheroidal cementite with equipment having too low resolving power and always finding the structure lamellar at 500 diameters. Many months later, after replacing the equipment with improved apparatus of higher resolving power many of the lamellar structures were found unmistakably to be entirely spheroidized. Whether the resolving power of the equipment used for studying structures at 3000 diameters and higher magnifications are sufficiently refined to resolve very small particles of cementite as spheroids has not been made quite clear to me. But aside from the question of whether these so-called "fine pearlite" structures are actually lamellar or not they are not what I like to call "pearlite". I should rather call them "pearlitic-sorbite" or "pearlitic troostite" to differentiate them from the structures of drawn martensite which, along with you, I like to call simply troostite or sorbite. I could easily agree to the terms "primary" and "secondary" to distinguish the two.

It brings about an impossible situation to call all lamellar structures, regardless of composition, "pearlite". This structure is not characteristic of steel, but may be found in non-ferrous metals as well.

Francis B. Foley
Supt. Research Department.

The Midvale Co.,
Nicetown, Philadelphia.

Metallographic Examination of Sheet and Strip

To the Editor: Regarding my letter to the editor on p. 182 of the July issue, we have been informed by the Hercules Powder Company that "Tornesite" is not a synthetic rubber but chlorinated natural rubber. This note of correction may be of interest.

Arthur L. Sanford

Battelle Memorial Institute,
Columbus, Ohio

A Chuckle

A Chilly Subject

To the Editor: Although the following should be taken up with the Fundamental Standards Committee of the National Research Council, it might be well to air it first in your "Chuckles" column.

One of those roving steel salesmen dropped in to declaim the virtues of their specially processed steel which, due to its treatment, out-wore competitor's steel 2 to 1 even though the latter was fully heat treated.

" . . . and whatever they do to it, I don't know. They will not tell me and I cannot find out," said the salesman.

"What are its impact properties at low temperatures?" I wedged in.

"Impact properties? Impact properties . . . well, I guess you got me there. I must admit I don't know."

So a month later up he popped again, but this time with the V. P. in charge of metallurgical operations.

"You inquired about the impact values of our steel, I believe," continued the V. P. after enlarging upon the salesman's story.

"Yes. What are they?"

"You wanted values at low temperatures and we really have them. At 800 deg. F. . . . "

"I am only interested in low temperatures," I interrupted.

"That's what I mean, 800 deg. below zero Fahrenheit!"

"Gosh! That's awfully low! Didn't you have trouble attaining that temperature?" I asked in amazement.

"Oh, yes! It was quite a problem, but they made a special effort for us and really got the temperature down."

All I can say is that physicists are pikers. They work their fool heads off and never actually reach —460 deg. F.

I would like to know who is president of the company. He must be some close relative of lying, lumbering Paul Bunyan.

LaFayette.